



## Guide for contributors to the Australian Journal of Education in Chemistry

### Introduction

The Australian Journal of Education in Chemistry publishes refereed articles contributing to education in Chemistry. Suitable topics for publication in the Journal will include aspects of chemistry content, technology in teaching chemistry, innovations in teaching and learning chemistry, research in chemistry education, laboratory experiments, chemistry in everyday life, news and other relevant submissions.

Manuscripts are peer reviewed anonymously by at least two reviewers in addition to the Editors. These notes are a brief guide to contributors. Contributors should also refer to recent issues of the Journal and follow the presentation therein.

### Articles

Articles should not exceed six pages in the printed form including tables illustrations and references - ca. 5000 words for a text only document. Short, concisely written articles are very welcome. Please use headings and subheadings to give your article structure.

1. We prefer to handle all submissions electronically. Our preference is for Microsoft Word files in Mac format. However, you can send files from any common Windows, DOS or Macintosh word processor.
2. On another separate page provide an abstract of 50 to 100 words;
3. All photographs should be scanned and saved in JPEG format.
4. All chemistry structures, and schemes should follow the guidelines set for ACS publications. It is preferred that Schemes, Tables etc be arranged to fit in a column 7 cm wide, although full page width will be accepted.

### Reference Styles

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## In this issue .....

In response to the Government White Paper on research and research training, **Harding** presents a framework for effective postgraduate supervision, including timely completions, via communication in a collaborative culture. Strategies to ensure open communication and conflict resolution are presented, as is a platform to develop scientific writing skills that results in minimal thesis preparation time and readiness for publications. The treatment of a postgraduate student as a professional collaborator underpins this strategy and facilitates the transition from student to independent researcher. As in so many facets of our lives, communication is seen as the key ingredient.

Effective communication is also at the heart of a programme described by **Tronson and Ross** in developing skills amongst those involved in first-year teaching to help improve the learning environment for the students. The motivation has been the view that the teaching teams deserve more support and respect than merely being expected to 'pick it up along the way', 'read about it in the library' or 'teach the way they were taught'. They describe team meetings used as a model situation in which members share experiences, observations, ideas and opinions so that, with opportunities for reflection, pedagogical practices and knowledge that have been developed are used to create a 'learning community' in the teaching laboratory.

**Vuthaluru, Doshi, White and Tade** have recognised that chemical engineering students may not perceive the relationships between the various components of their course, because they are often presented in isolation. They have created a 'spider-web' diagram as a guiding tool to give students a holistic overview of their programme,

enabling them to understand better the journey they are undertaking.

**Buntine, Kable and Metha** present another experiment in the APCELL database. They describe and evaluate an exercise based on identification and analysis of the electronic emission spectrum of the  $C_2$  radical formed in natural gas/oxygen flames. Students at the higher levels of undergraduate chemistry courses can analyse the  $C_2$  spectrum in terms of quantum theory of electrons and vibrations of a diatomic molecule to estimate the force constant and bond order of  $C_2$  in both ground and excited states, and to reconcile these with molecular orbital theory predictions. In addition, by measuring the relative abundance of  $C_2$  in various regions of the flame, students can gain insights into the chemistry of the combustion process. This experiment is rich in possible learning outcomes, ranging from spectroscopic and bonding knowledge, to process, practical and generic skills – all of which have been listed in the evaluation component of the paper.

In another experiment evaluated through the APCELL programme, **Wajrak and Rummey** describe the determination of silver ions in aqueous solution by differential pulse anodic stripping voltammetry. By carrying out this experiment, students can gain better understanding of the ASV method by investigating the effect of accumulation or deposition time, performing chemical pre-treatment on the working electrode, analysing samples which contain two metal ions with similar stripping potentials, determining the difference in accuracy between two calibration methods (external standards, and standard addition), and finally analysing a given water sample containing an unknown quantity of silver ions.

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## Guest Editorial - Off to a Good Start

Off to the AFL match! At half-time the pitch is covered with junior players enjoying practising the game in front of thousands. This is just one sign of something sports organisations have become very good at doing: nurturing young players spotting talent and ensuring an audience in the future.

Do we do the same thing in chemistry? I suggest that we should take a closer look at what is going on at the “junior” level because there is a lot of action in this area of education at the moment, and the word “chemistry” does not come up very often.

A few moments exploring a bit of the educational landscape shows why. Unlike maths and language education, chemistry (science) education has always been top down. Historically it was introduced at high school and has never been a major focus in early primary school. This makes senior primary and junior high school the only opportunities for reaching all students because most students do not take chemistry (science) beyond the compulsory years.

This educational phase has been captured by the middle years of schooling movement. It has been gaining momentum during the past decade in Australia and has a longer history, albeit in a slightly different form, in the USA. The words that echo round in the movement include “integrated curriculum, higher-order thinking, success for all, relationships and identity” as well as literacy and numeracy. The movement’s focus on the adolescent and his or her needs, addresses a range of important issues such as disengagement from school, a common feature of this period.

On the other hand we (as chemists) have difficulty imagining life without a chemical background. We are bombarded with news about global warming, the molecularisation of almost every biological thought, and information about drugs and other medical advances. At the same time it is obvious to us just how usefully chemistry can inform the adolescent making their personal exploration of the world.

The question for us is: “Does the chemistry in the science curriculum inspire students usefully for life in the 21<sup>st</sup> century?” “Well in patches,” would be my response because there are inspiring examples, but the traditional curriculum does not fit well with the new setting.

We can look at a few examples of why the match is often poor:

- **Big ideas** - Books canvassing the useful big ideas of science always single out the molecular nature of matter whether they are written by scientists or

interested observers such as Bill Bryson. While we have to be careful to deal with non-molecular substances honestly, the over-riding idea of molecularity is the key to understanding materials and chemical change. Of course it is a difficult concept that needs lots of rehearsal over an extended period (years). However, a sample of common science texts shows that the concept is often introduced late, given modest rehearsal, and buried amongst a welter of minor concepts.

- **Alternative conceptions** – While the historic approach is an attractive one when introducing



Middle years classes often do not have laboratories and specialist science teachers.

concepts, it can easily lead to misconceptions that make a challenging piece of learning more difficult. The classic example is the Bohr atom, given unnatural prominence in the curriculum because it teeters on the brink of the quantum world. The result is thousands of students walking round with mental images of minute planetary atoms, a very poor platform for launching into an elementary understanding of chemical bonds.

- **Inappropriate resources** – Many teachers exploring middle years teaching have weak backgrounds in science and especially chemistry. As generalist teachers they face the problem of developing integrated units of work that cover aspects of up to eight different disciplines. Traditional science textbooks that assume a single discipline focus are inappropriate in this setting. The teaching context is particularly complex because students are encouraged to contribute to a negotiated curriculum which requires a more extensive background of the teacher.

Happily there are factors combining to help the position such as the widespread use of the internet by teachers and students and the supply of specific science resources aimed at the middle years being published in the United States by organisation such as the American Chemical Society. While, in this case, the setting is different there is common interest and the resources provide examples to inspire local initiatives.

But the bottom line is a need for greater participation by chemists (us) at this level so that the curriculum becomes infused with activities that capitalise on the current technologies and give glimpses of chemistry as the exciting expanding discipline that it is. In particular we need to help by providing the links between the topics and the major chemical principles so that curriculum has rigour at a level appropriate for the student audience. It is only by our participation that we can show we have learnt the lesson about nurturing young “players” as effectively as the sporting clubs.

Tony Wright, UQ

# **Collaboration and Communication: Two Essential Components of Effective Higher Research Degree Training in Chemistry**

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## **Abstract**

In response to the Government White Paper on research and research training, the scrutiny of education of postgraduates in Australia and higher degree supervision has been intense. In contrast to non-experimental based disciplines in the social sciences and humanities, the planning and execution of research in experimental based areas such as chemistry allows the development of well-defined structured research goals. This article presents the framework for successful supervision in chemistry and cognate disciplines, including timely completions, via communication in a collaborative research programme. Strategies to ensure open communication and resolve conflict are presented as well as a platform to develop scientific writing skills that results in minimal thesis preparation time and publications. The treatment of a postgraduate student as a professional collaborator underpins this strategy and facilitates the transition from the student to the independent researcher.

## **Introduction**

It is now 5 years since the Government White Paper on research and research training in Australia was published.<sup>1,2</sup> The implications of the policy presented in the White Paper for postgraduate supervision and the need for change to address criteria presented in the paper and attract performance based funding, have attracted significant debate in tertiary institutions in Australia.<sup>3</sup>

A significant outcome of the White Paper has been recognition by Australian Universities of the need to critically review postgraduate supervision, and to assess both the merits and limitations of the systems in operation in the eighties and nineties. However, in contrast to the significant literature on pedagogy in undergraduate tertiary teaching, the literature on graduate or postgraduate education is significantly smaller. This is undoubtedly related to the diverse opinions on what constitutes a doctoral degree, and the diversity of research methods and supervisory styles that are well-recognized and are the hallmarks of academe. There are some studies on student experience in the UK,<sup>4,6</sup> and some literature relevant to the Australian context pre 1999. However, postgraduate supervision needs to be reassessed in light of the White Paper and current pressures felt by both academics and students, in order to ensure high level research education. In this regard, a number of more recent articles directed at the Australian experience have been published.<sup>7,8</sup>

In this paper, strategies that allow effective supervision of chemistry postgraduates in the current climate are discussed. Chemistry, as a scientific and largely experimental-based discipline, with a well-defined logic allows the development of research skills, and independence in a manner that is distinct from research in the social sciences and humanities. This article proposes that the two essentials to successful education of postgraduates, including timely completion, are collaboration and communication. Treatment of research students as professional collaborators ensures open, free dialogue with mutual respect for the opinions of both parties, and facilitates a working partnership in which the student takes ownership of the research and, in so doing,

develops critical scientific research skills. Communication is an essential component of a professional working relationship, and oral communication and scientific writing skills are equally important in graduate training. Adherence to these two principles provides the framework for development of tailored programmes that accommodate student needs and facilitates the progression to PhD graduates who are independent, critical thinkers with scientific integrity and confidence in their ability and skills to tackle any new research problem.

## **Collaboration and Communication**

Collaboration in this article is used to refer to the working relationship between the supervisor and student. Many of the difficulties that arise in candidatures are related to poor communication between the supervisor and student, which is viewed as a leader/subordinate relationship. Indeed the term "supervisor" widely used in Australia enhances this connotation. In any supervisor/subordinate relationship, the subordinate partner, in this case the postgraduate student, has an implied traditional subservient and compliant role. The term "advisor" is more common in the USA and presents a more equitable image of the partners in the working relationship. Having defined these terms, the words "supervisor", "advisor" or "collaborator" are labels only; the important information is what these labels define, or translate to, in research supervision.

The term "research collaborator" has a positive implication of a partnership based on equity, with each party making significant, independent contributions to the research programme. Before commencement of a collaboration with a colleague or another laboratory, standard procedure by an experienced academic researcher would be to establish the nature of the collaboration including the research plan, timeline, funding, publication and authorship, intellectual property issues and development of a plan for exchange of personnel or provision of samples or expertise to the partnership. Subject to satisfactory agreement on these issues, a partnership is entered into which is underpinned by professionalism i.e., work attitude, ethics and communication at the level expected by professional scientists is assumed as a basis for a

productive collaborative programme. The same principles, if applied at the commencement of a research higher degree candidature, provide a mechanism to ensure that the benefits of an established research partnership are translated directly to the higher degree experience. While the intellectual and planning contributions of the student to the partnership in the initial phases may be limited,<sup>4</sup> the professional nature of the working relationship should allow fostering and mentoring of skills to occur in a constructive learning process such that the transition of the student to a qualified research scientist is a seamless and continually evolving process over the 3-4 years of candidature.

Once a research partnership has been established, central to the successful research collaboration is the research project and expertise of the collaborators. This is no different to the plan for a PhD programme and effective

postgraduate research training is always based on the assumption that a well-defined, interesting and important scientific question is being addressed. In addition, discipline expertise is required to guide the initial stages of the project. However, while expertise is essential to supervision, a recent study at the University of Western Australia (UWA), investigating the desirable characteristics of a supervisor,<sup>9</sup> found that students rank non-expertise related characteristics of supervision, which provide support and balance creativity with criticisms, as more important overall than expertise-related characteristics, i.e. characteristics that all stem from excellent communication skills.

Some examples of strategies in a *collaborative* partnership between supervisor and student, and the benefits of these processes, are summarized below.

**Table 1:**

<b>Process</b>	<b>Outcome</b>
<p><b><i>Prior to commencement of candidature</i></b></p> <ul style="list-style-type: none"> <li>establish expectations, including feedback and communication mechanisms in writing and agreed to by both parties</li> <li>Involve an associate supervisor or independent person in process to ensure all relevant issues have been aired</li> </ul>	<ul style="list-style-type: none"> <li>avoids conflict in the candidature through misunderstanding of expectations</li> <li>provides a non-confrontational mechanism for student to request supervisory arrangements are changed at first year review or anytime in candidature</li> </ul>
<ul style="list-style-type: none"> <li>ask opinions (even if you know the answer)</li> <li>avoid telling student what to do or providing all the answers</li> </ul>	<ul style="list-style-type: none"> <li>confidence-building mechanism for student to express opinion</li> <li>encourages independent thought and expectation that student will contribute to discussions</li> </ul>
<ul style="list-style-type: none"> <li>never be dismissive of any proposal or suggestion put forward by student</li> <li>if proposal is flawed, establish how student arrived at proposal first, then suggest alternate strategies or pose questions that will direct student to reach different conclusions</li> </ul>	<ul style="list-style-type: none"> <li>promotes independent thought</li> <li>teaches problem-solving strategies</li> <li>encourages student to express ideas without fear of prejudice</li> </ul>
<ul style="list-style-type: none"> <li>accept that personal problems and/or work will affect performance of student at times</li> <li>acknowledge that personal and/or work problems will affect supervisor performance</li> </ul>	<ul style="list-style-type: none"> <li>reinforces respect and professionalism that acknowledges human side of student</li> <li>reinforces equal partnership in collaboration</li> </ul>
<ul style="list-style-type: none"> <li>applaud good ideas and solutions</li> <li>reward extra effort</li> </ul>	<ul style="list-style-type: none"> <li>transmits enthusiasm</li> <li>builds confidence and motivation to succeed</li> </ul>
<p><b><i>Promote open and free dialogue</i></b></p> <ul style="list-style-type: none"> <li>be honest regarding performance</li> <li>give student opportunity to respond to criticisms and be prepared to reassess your appraisal based on this information</li> <li>if disagreement, always clear the air</li> <li>if disagree on science, seek independent arbitrator (associate supervisor); resolve issue to all parties satisfaction asap</li> </ul>	<ul style="list-style-type: none"> <li>avoids confrontation, and resentment that can result if there is a heated argument or disagreement on certain issues</li> <li>by encouraging student to seek independent input, reinforces role of supervisor as an advisor</li> </ul>
<ul style="list-style-type: none"> <li>include students in discussions with visiting academics</li> <li>introduce students to speakers at conferences</li> </ul>	<ul style="list-style-type: none"> <li>reinforces treatment as research collaborator</li> <li>places research in international context</li> </ul>
<ul style="list-style-type: none"> <li>establish formal mechanisms whereby student can obtain additional advice, expertise, or access to resources</li> </ul>	<ul style="list-style-type: none"> <li>avoids frustration at not understanding impact of work or concerns that research is not in proper context</li> </ul>
<ul style="list-style-type: none"> <li>encourage presentations at conferences and lectures</li> </ul>	<ul style="list-style-type: none"> <li>research placed in international context</li> <li>importance of science in field reinforced</li> <li>training in communication skills</li> </ul>
<p><b><i>Lead by example by application of the same set of standards to supervisor and student</i></b></p> <ul style="list-style-type: none"> <li>advise of lecture schedules or absences in advance</li> <li>acknowledge that there will be times that you will not be available but ensure that in these situations some channels for communication advice are in place</li> </ul>	<ul style="list-style-type: none"> <li>instils professionalism in attitude</li> <li>results in collaborative relationship</li> <li>reverse expectation that student extends same courtesy is set by example</li> <li>avoids dissatisfaction by misconception that supervisor is unavailable/too busy</li> </ul>
<ul style="list-style-type: none"> <li>acknowledge effort in positive way (even if the outcome is poor)</li> </ul>	<ul style="list-style-type: none"> <li>builds confidence</li> <li>reinforces interest and awareness of limitations</li> </ul>
<ul style="list-style-type: none"> <li>acknowledge your weaknesses and accept criticism of yourself as a supervisor</li> </ul>	<ul style="list-style-type: none"> <li>sets example to student</li> </ul>

### **Scientific Writing**

Scientific writing is an essential communication skill required to produce a PhD or MSc thesis and is a generic skill expected by employers. How does one teach scientific writing and enable a student to progress to the level of competency required to draft manuscripts and thesis chapters in a time-efficient and constructive manner? Frequently, the perception of students is that the experimental results and new discoveries are the most important activity in research. Development of writing skills in parallel to experimental work, in order to cogently and concisely report on the research is essential to research training and the thesis and supervisors must address this issue early in the candidature. In particular, the diverse levels of written English skills that exist in the postgraduate cohort need to be recognized. These skills may vary from full command of grammatically correct English, to students for which English is a second language and students who struggle with the often apparently illogical grammar and structure of the English language.

Strategies aimed at engaging student participation and confidence are an integral part of both written and oral scientific expression. Presentations of research summaries in small group meetings to an expert audience, at the School/Department level to peers and academics in the broader discipline, through to conferences, are extremely valuable to the thesis and publication writing process. Most chemistry students in Australia are exposed to a diverse range of research seminars during the course of their candidatures. Students and supervisors are well able to recall "good" seminars as well as those assessed as a poor use of time because the presentation was uninteresting and not able to be understood. Thus, most students can identify the criteria that distinguish impressive seminars. These factors include identification of the research problem, placement of the research in the context of the field, the logic behind experiments, the results, interpretation of results and conclusions. Personality and personal style also contribute to oral presentations, but most students will equally recognise that these elements alone are not sufficient for an excellent lecture; a highly animated presentation in which the material is presented illogically with no firm aims or conclusions is recognised as such by the audience. Encouraging a critical review of lectures is an efficient way of engaging reflective thought by the student on the style, logic and science of the presentation. Such reviews provide a platform to enhance student presentations and writing skills, via constructive criticism, to ensure the science is accurately and professionally presented. The same logic applies to scientific writing.

The advantage of scientific writing in an experimental science such as chemistry, compared to the humanities, is that the style of most journal publications follows a structured presentation of Introduction, followed by Results, Discussion and some Experimental Methods. Indeed, reading such research papers is integral to any research programme, yet students often take for granted the fluidity and clarity of the writing. Assessment of research papers in order to appreciate how the research background has been presented, and the distinction between results, and discussion of the implications of results, is extremely important in presenting cogent arguments. Equally well, students frequently criticize papers for being inaccurate or unclear in explaining methodology or experimental procedures. These criticisms provide an excellent opportunity for supervisors to direct students' attention to these deficiencies and give them the opportunity to highlight how the paper could have been improved for the scientific community by revision. This process is the first stage in journal refereeing and also instils the professional responsibilities that scientists have as referees for the published literature. Correct scientific expression to distinguish between a fact, data that is consistent with a known fact, a firm conclusion, or a prediction are also extremely important when describing results of reactions and in the interpretation of spectra. These examples are best illustrated by application to the student's own research results.

The preparation and receipt of critiques has been recognised at the most influential element in helping doctoral students in the USA understand the process of scholarly writing and in producing a better written product.<sup>10</sup> The method of feedback was also identified as important, with personalized face-to-face feedback and iterative critiques of writing. While recognizing the limitations of this study acknowledged by the authors, the general principles do apply in chemistry. A personal discussion of a written critique of a draft manuscript allows the student to participate in development of a structured, accurate argument, for example, by allowing the merits and limitations of different terminology to be explored. Written critiques alone frequently contain red lines through text, and can be particularly demoralizing to the student.

Processes that aid in the development of good scientific writing skills include:

Table 2:

Process	Outcome
Identify purpose of the written document (journal article, experimental, thesis chapter)	<ul style="list-style-type: none"> <li>• directs style and focus</li> </ul>
Direct student to prepare initial drafts of major headings only with dot point forms of key chemistry for discussion	<ul style="list-style-type: none"> <li>• avoids student including irrelevant material or too much detail through inexperience</li> <li>• provides framework to provide constructive direction</li> <li>• reduces red pen and crossing out that demoralizes students</li> </ul>
For poor or non-scientific expression, ask student to verbally describe point; acknowledge good parts and then together translate this to phrases	<ul style="list-style-type: none"> <li>• facilitates constructive criticism, and a learning experience, rather than implied negative</li> </ul>
Ask student to compare final document, after several iterations, with original document	<ul style="list-style-type: none"> <li>• illustrates alternate ways of expression and highlights key points overlooked in initial drafts</li> <li>• allows contrast between colloquial and scientific expression</li> <li>• allows student to readily recognize overly verbose language and scientifically incorrect statements</li> </ul>
Publish work as it is complete	<ul style="list-style-type: none"> <li>• ensures work is complete and identifies any further experiments that are required</li> <li>• publications provide complete thesis chapters</li> <li>• provides student with ownership and verification of importance of work</li> <li>• removes review of a single large document (thesis) by supervisor at the end of candidature</li> </ul>
Require written report (or draft publication) every 6 months	<ul style="list-style-type: none"> <li>• develops forward planning skills to meet a defined deadline and thus an awareness of time management for thesis submission</li> <li>• promotes sense of achievement or allows student to recognize that progress has not been satisfactory</li> <li>• generic skill research planning</li> </ul>
Provide feedback on all documents that includes evidence that the document has been critically assessed	<ul style="list-style-type: none"> <li>• reinforces professional respect</li> <li>• evidence that effort and time invested by student has been appreciated by supervisor</li> </ul>
If appropriate, publish a review article on thesis topic	<ul style="list-style-type: none"> <li>• serves as thesis introduction</li> <li>• ensures candidate is up-to-date with all literature</li> <li>• builds confidence and enthusiasm as publications arise</li> <li>• "literature review" provides a tangible outcome</li> </ul>

### Generic skills

The first report of generic capabilities of postgraduate students in Australia has recently been published.<sup>11</sup> The generic attributes of postgraduates at graduation, programmes offered by Universities and students' perceptions of generic capabilities have been surveyed. Students acknowledge the importance of generic skills, some of which are acquired through research training, but emphasize that these must be placed "in the broad integrative framework that captures the richness and multiplicity of postgraduate research experiences".

Are these results relevant to Chemistry? Generic skills that would be expected by a chemistry graduate entering industry or academia include advanced research planning skills, occupational health and safety, intellectual property, scientific writing skills, communication, ethics, professionalism and scientific integrity. Chemistry postgraduates should acquire many, of not all, of these skills automatically during their research candidates. These generic skills form the basis of any productive research collaboration, and as such, treatment of the student as a collaborator provides a mechanism to ensure that many generic attributes are acquired and improve during the course of the candidature.

### Applications

The development of standard supervision guidelines for all students does not recognize the diverse skill and expertise base, and the needs of students as individuals. All students are individuals and tailoring of specific programmes via negotiation, recognizing both the strengths and weaknesses of each individual student, is essential. Thus, implementation of all the guidelines presented in the tables above does not guarantee a "successful" candidature. The Government White Paper is based on the assumption that students' research performance (as well as the supervisors' performance) is not affected by personal, health or financial worries. Day-to-day issues will always impact sometime during a research candidature. The critical intervention required by a supervisor is to recognize when there is potential for a significant detrimental impact and to respond accordingly.

Resolution of conflict is essential if a good working relationship is to be maintained throughout candidature. The mechanisms to resolve difficulties, however, are not "taught" and are therefore often very confronting when first encountered, particularly by an inexperienced supervisor or by a student. In a subordinate relationship, students are reluctant to criticize a supervisor who, for example, does not return thesis chapter drafts or reports in a timely fashion, or does not provide quality time with them. Supervisors, realizing that a student is working only

at the minimal level, may avoid confrontation to advise the student that increased effort is required, or while acknowledging a negative impact of other academic responsibilities on their supervision, fail to address the issue. These issues are often not raised through the implied negative effect that may affect their working relationship. The open lines of communication and a clear delineation of the responsibilities of the supervisor and student in the collaboration should facilitate honest and open resolution of conflict situations should they arise.

A key function of a supervisor is in year one of candidature and a frank and honest assessment of performance after year one of candidature is essential, avoiding/resolving conflict situations (discussed further below). A key role of the supervisor is to exercise judgement in negotiating the research plan for the next 6 month period. If a critical

goal estimated to be complete in 3 months has not been complete after 9 months, then the reasons for the time difference need to be reviewed. Unexpected results, or the unexpected discovery of a new research direction could be the reason. However, a lack of experimental skills, failure of equipment, absence of appropriate expertise, or lack of expected effort by the student are critical factors in a recommendation by the supervisor to continue the proposed plan or proposing a change in research directions. Students rely on this advice and, provided they participate in the decision making process and negotiate a way forward, should view this as a positive resolution of difficulties and a way to ensure upward progress.

Some examples of potential conflict situations that can occur, and resolution by communication, based on a collaborative partnership are listed below:

**Table 3:**

Potential Conflict Situation	Resolution
Lack of time - student perceives that supervisor too busy or that quality time is not available	<ul style="list-style-type: none"> <li>• make appointments every 4-6 months in which one hour minimum of uninterrupted time is reserved for student</li> <li>• summarise meeting by email and ensure that the student is happy that issues have been addressed and a plan agreed to for issues that have not been resolved at that time</li> </ul>
Long hours of work by student not reflected in output	<ul style="list-style-type: none"> <li>• arrange formal meeting with student</li> <li>• summarize your perceptions and rank output relative to other students at same level to highlight deficiencies</li> <li>• establish reasons for low output including student reviewing his/her performance e.g., poor time management, lack of interest, personal problems.</li> <li>• develop a focused 4 week plan with clear objectives to address concerns</li> <li>• agree to review progress in 4 weeks and include a plan as to consequences if output has not improved</li> </ul>
Depression as things don't work escalates to low morale and low productivity	<ul style="list-style-type: none"> <li>• confirm that personal issues are not also contributing to situation</li> <li>• negotiate with student the pros/cons of taking time out, and/or of working on another aspect of project for some time before revisiting present work</li> <li>• reassure that tenacity to persevere through tough problems is hard and experienced by all researchers</li> <li>• negotiate a plan B should things not improve</li> </ul>
Student does not receive feedback from supervisor on written report or thesis chapters are not returned in timely manner	<ul style="list-style-type: none"> <li>• avoid this situation by explaining up-front time commitments, including heavy teaching, and impact this will have on time to return material</li> <li>• develop a staggered plan for thesis writing in which student agrees on dates to supply given chapters and supervisor agrees on timeframe to return corrected work</li> <li>• always keep student informed if unexpected work duties interfere with agreed timetable</li> <li>• published work shortens whole process as supervisor should not need to check or correct chapters</li> </ul>
Lack of focus leads to lots of ideas with nothing ever finished	<ul style="list-style-type: none"> <li>• appointment with student and request a summary of what has been achieved</li> <li>• highlight positive aspects but point out deficiencies that will prevent publications and inclusion in thesis</li> <li>• negotiate plan to complete ideas and tailor feedback mechanism to ensure that regular checks on progress made</li> <li>• emphasise the training aspect as a scientist and importance of completion of work</li> <li>• closely monitor over next 2-3 months</li> <li>• involve an associate supervisor if student feels demands are unreasonable; independent advice from other researchers should be encouraged</li> </ul>
Poor communication skills	<ul style="list-style-type: none"> <li>• scientific writing skills as described in section above</li> <li>• after 18 months clear evidence that thesis can be written must be evident or a MSc degree should be recommended; encourage student to seek independent opinions if necessary</li> </ul>
Nervousness and lack of confidence at oral performances	<ul style="list-style-type: none"> <li>• provide forums for practice presentations in group meeting presentations</li> <li>• ensure constructive criticisms provided</li> <li>• positive reinforcement by acknowledging improvements with time</li> </ul>
Criticism by supervisor is viewed as a personal attack	<ul style="list-style-type: none"> <li>• ensure that obligations and requirements of supervisors in University policy are explained</li> <li>• devolves the situation to a component of your job rather than a personal attack</li> </ul>

### Summary and Outlook

The impetus for this article has arisen from the author's experience as a research supervisor in chemistry and extensive interactions with postgraduate students within a large School of Chemistry and across many disciplines in a large Faculty of Science. The strategies presented, based on communication and collaboration, are based on personal experience in interacting with this diverse set of postgraduates, and in an effort to maximize productivity as an academic with increasing teaching and administrative workloads that necessarily impact on time for research including supervision.

There is no single set of rules for good supervision, and outstanding research supervision is difficult to define and equally difficult to assess. The well-developed undergraduate pedagogy which includes surveys, feedback mechanisms, iterative improvements and assessment of these changes on student learning, are not applicable to the research environment. Factual criteria such as entry level qualifications, length of candidature, research publications, conference presentations are necessary but not sufficient to demonstrate outstanding research supervision. Indirect indicators may be informative and provide more insight into the training a student has received e.g. feedback from a subsequent employer or postdoctoral advisor on a student's problem-solving skills, confidence, integrity and research aptitude. Student surveys during and after candidatures are also useful but not quantitative. At a personal level, the best feedback is that directly received from a student on completion of a higher degree.

In writing this article, it is recognized that supervisor development is equally important as supervision skills. In a major change since the last decade, this issue is being addressed by most Universities via workshop training, probation and access skills.<sup>12</sup> Thus adaptable supervision, in which supervisors recognize their responsibility to expand skills as leaders and educators is important, as is active mentoring and training of new, inexperienced supervisors. Whether these tools translate to more effective supervision, or more personalised mentoring in an

individual discipline such as chemistry, is yet to be seen. As with supervision in general, quantitative indicators to critically assess the impact of these supervisor development programmes will be difficult to establish. Feedback from the first round of PhD graduates who commenced degrees in the post White Paper era, and employers of these graduates, is awaited with interest.

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# An invitation

**The editors invite readers to make contributions to this Journal. As well as papers submitted for peer review, we welcome any of the following:**

- **Short papers on chemistry topics or concepts, from an educational perspective**
- **Reflective papers teaching and learning chemistry - general or specific**
- **Letters to the editor**
- **Announcements**
- **Forthcoming events**
- **Books to review**
- **News about people or places**

# Modelling effective teaching and learning strategies with our teaching teams in first-year university

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## Abstract

This paper describes some ways in which we have attempted to encourage all members of our teaching teams to help improve the learning environment for the students at first-year university level.

We have:

- modelled for our teaching teams the attitudes and strategies we have developed;
- listened to each other during discussions of complex concepts, thus encouraging collegiate sharing of information;
- empowered members of our teaching team to use their own imagination, and to be comfortable trying out novel and innovative teaching strategies.

These outcomes have been supported by observations of behavioural changes in laboratory sessions and tutorials and reflection on a range of evaluations over several years.

*“The average teacher tells.  
The good teacher explains.  
The superior teacher models.  
The great teacher inspires.” Anon.*

## Introduction

This paper describes some ways in which we have attempted to improve the learning environment for students at first-year university level by encouraging all members of our teaching teams to adopt effective teaching strategies.

Our teaching teams have included tutors<sup>1</sup>, laboratory demonstrators<sup>2</sup>, laboratory supervisors<sup>3</sup>, the technical staff responsible for some of the first-year science laboratories and several guest lecturers. Over the years these teams have been fluid and diverse; numbers within the cohorts of students varies between 150–450 in each unit, and many in the teaching team have been employed on a casual (sessional) basis. There is no ‘standard profile’ of these teaching team members except that many of them are postgraduate students with varying prior experiences in teaching; most of them have little training in pedagogy although they may have attended one of the orientation workshops facilitated by the Educational Development Centre at UWS; and a minority of them are experienced tertiary teachers, researchers or industry personnel. It is often these tutors and laboratory demonstrators, however, who are responsible for the small-group teaching situations

<sup>1</sup> Tutors take weekly tutorials of 15–25 students; although the theme and suggested exercises are set by the unit co-ordinator, each tutorial group reacts differently so tutors have freedom to develop their own teaching styles.

<sup>2</sup> Demonstrators are usually responsible for helping a group of 12–15 students work effectively within a total laboratory group of 30–60 students. The laboratory exercises are pre-determined, but there is scope for demonstrators to develop small-group interactions and discussions to facilitate the learning experiences of the students.

<sup>3</sup> Supervisors are responsible for the general running of the laboratory session, including supervision of other demonstrators, delivery of any pre-laboratory demonstrations regarding theory, experimental technique and/or safety issues and liaison with the technical staff and the unit co-ordinator. Each is also one of the demonstrators within that session.

in which students have the opportunity to undertake their most effective learning.<sup>1,2</sup> Both authors have been responsible, as unit (subject) co-ordinators, for first-year chemistry and biology units. Students may be taking both our units or only one; some students are science ‘majors’ and some are students of horticulture, food sciences or environmental studies and will not be taking chemistry or biology in second year.

Within the traditional teaching situations of lectures, laboratory sessions and tutorials, we have infused a student/learner-centred approach as an overarching theme for the teaching and learning practices that we develop, implement and reflect upon. As part of these practices, we have searched for ways to provide the ‘beginning teachers’ in our teams with the skills necessary to develop an effective teaching and learning environment with their own students. Our teaching teams deserve more support and respect than merely being expected to ‘pick it up along the way’, ‘read about it in the library’ or ‘teach the way they were taught’. Sessional staff usually have neither the time nor the pedagogical experience to read and make meaningful understanding of the many publications on teaching strategies or theories. This lack of time and financial resources, a situation similar to many tertiary institutions, also prevents us from implementing one-on-one mentor relationships and other intensive peer evaluations that could form the scaffolding for a more formal program. We could have perhaps modelled the pre-service teacher education in primary and high schools, but our reading of the literature indicates that this ‘practicum’ may not be directly appropriate in the tertiary situation;<sup>3–6</sup> also, some authors, such as Cairns and Eltis<sup>7</sup> and Rowley,<sup>8</sup> report that the modelling of teaching practices by supervising teachers in schools is sometimes perceived to conflict with the pedagogy the student teachers are being taught at the tertiary institution.

Many examples of literature aimed at tutors and demonstrators in tertiary education do not discuss science teaching specifically<sup>9,10</sup> or are ‘tips for tutors’<sup>11–13</sup> which, although useful, seem to advocate ‘instant answers’ for

tutors or demonstrators and are inadequate for us to build a more sophisticated teaching/learning community for our teaching teams. Other publications advocate only one type of approach or philosophy<sup>14,15</sup> and some are not relevant to the Australian situation.<sup>16</sup>

We have developed a 'model' of our teaching preparation strategies using the available literature on teaching and learning in order to explain its relevance to our teaching teams within our own context. In this paper, we describe our approach, a refinement of this type of modelling, that has helped our tutors and demonstrators become more familiar with a wide range of effective teaching strategies, given them the confidence to apply flexible approaches to their teaching and through using their own experience and personalities, allowed them to cater to the particular needs of their students.

All the strategies described are applicable to a wide variety of tertiary educators. Although one of the authors 'happens to be' a biology educator, and the other 'happens to' teach a range of chemistry and biochemistry units, this does not prevent both contributions being relevant to chemistry education. With the common aim of encouraging tutors and demonstrators to help students understand fundamental scientific concepts, both authors have successfully included some of each others' complementary strategies.

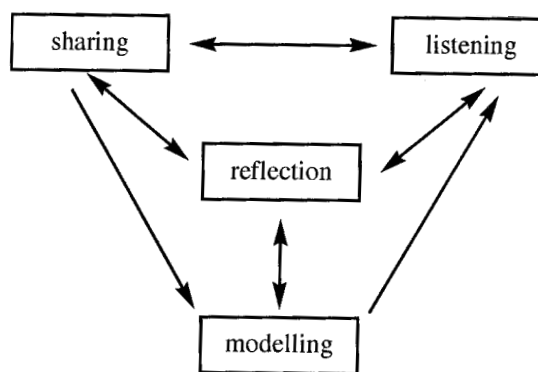
The overall approach that we have developed arose from answering the following questions which we will address within this paper:

- How can we help our teaching teams be more effective in helping our students learn concepts they find difficult?
  - *By creating a 'community of learning' within our teaching teams; by SHARING information and ideas about teaching strategies.*
- How can we ensure our personal 'insights' or particular idiosyncratic teaching techniques are effectively conveyed to students by our teaching teams?
  - *By MODELLING various teaching situations with our teaching teams; using the techniques we expect them to use with students.*
- How do we know what learning environment our teaching team members are creating in their small group teaching situations?
  - *By asking the tutors their ideas and LISTENING to their answers.*
- In summary, how can we help our teaching teams to use all their own experiences to improve the learning environment for our students?
  - *By endeavouring to INSPIRE our teaching team members to continually monitor and improve their own interactions with their students.*

A possible description of how we interact with our teaching teams is as follows:

### Sharing Information

Encouraging our tutors and demonstrators to be open and forthright about their own experiences is only useful if, ultimately, it improves the learning experiences of students.



One example of sharing conceptual information within the biology teaching team emerged after a meeting in which a tutor confessed "I always had trouble with that concept" and others at the meeting began contrasting 'conventional' and 'innovative' explanations that they had found useful or unhelpful. Because of the supportive atmosphere during the discussion, all participants subsequently felt confident enough to use similar teaching strategies with their students, where they tried sharing information rather than didactically supplying an answer. Since then, we have noted several specific instances where similar teaching techniques have encouraged team members to help the students in a more meaningful way. Three of these are described.

During a chemistry lecture on acetals and ketals, the students commented that one of the other tutors could explain the concept in a particularly adept way. This tutor was then given the opportunity to share her style of explanation with the whole teaching team at one of the regular meetings. All the team members (including the lecturer) were able to absorb aspects of her animated presentation, which subsequently helped everyone explain these concepts more effectively within their own student groups.

The biology team analysed the way photosynthesis is 'usually' taught and found it lacking in conceptual clarity. Using diagrams, team members contributed the aspects of their understanding that they felt comfortable discussing. Ultimately this resulted in a new laboratory exercise being developed which used a model along with explanations to visualise the various chemical reactions involved in the photosynthesis process. Because everyone in the teaching team had become more confident in their ability to explain complex concepts, they all felt better equipped to help students develop a deeper understanding of photosynthesis.

The chemistry team observed that one demonstrator was guiding a particularly ill-prepared group without ever making negative comments such as 'no' or 'that is incorrect'. Instead, she gently probed the students' own ideas, and patiently prompted them to expand on their limited conceptual understanding until they grasped some of the fundamental ideas for themselves and could proceed on their own. The discussion of these teaching techniques

helped the whole team to reflect on their own interactions and to become more aware of how to help their students.<sup>17</sup>

### Modelling effective teaching practices

As we have become more aware of the interactions between the tutors and demonstrators within our teaching teams, we have noted the advantages of deliberately modelling techniques that we expect them to use with their own student groups. Three examples of these strategies are given.

The main feature of the chemistry team meetings is that ideas and comments from the whole group are actively encouraged by the co-ordinator's continual questioning (rather than 'telling' or continually relating only her own experiences). This has created an atmosphere in which everyone feels sufficiently safe to express his/her own opinions. Each person within the team can help each of the others clarify their ideas or solve problems. By experiencing this atmosphere for themselves, the tutors and demonstrators have become more confident in attempting the Socratic<sup>18</sup> 'questioning' approach<sup>19-21</sup> with their own students. The transferring of a consistent set of pedagogical practices from the 'model' situation (the team meeting) to the actual teaching situation in the laboratory has resulted in the development of a 'learning community' which encompasses the demonstrators and supervisor as well as the students. As we have progressively encouraged students to feel 'safe' enough to express their misconceptions, they have become more willing to accept help to investigate the implications of their own ideas. Students in these classes now expect fewer 'instant' or 'right' answers from the teaching team than has been observed in previous years.<sup>19</sup>

Facility in handling laboratory equipment requires practice. Sometimes it is observed that students have 'forgotten' these 'seemingly simple' skills, even though we have observed adequate performance within previous laboratory classes. The principle of guided instruction, described here to teach the use of a microscope, would be equally successful in teaching the use of any laboratory apparatus from a burette to sophisticated and delicate instruments. In this case, the guided instruction strategy was first modelled with the teaching team (acting as 'learners'), enabling them to critique the strategy and suggest modifications. Next, in the laboratory, the supervisor had the students 'act out' the process step by step as she showed them the correct technique, (eg "*now put your left hand on the xyz knob, like this ...*"). The demonstrators, for whom the process had been previously modelled, were confident in repeating this process with progressively smaller groups of students, then pairs of students 'instructed' each other, and finally each student attempted the process individually (with guidance if necessary). This process helped students to avoid 'overload' as described by the Information Processing model of learning<sup>13</sup> because it ensured they were focussed on the one skill for an allocated time, rather than attempting to 'pick it up' while simultaneously trying to learn other material. In one laboratory session, these students have achieved more supervised practice than a similar group who have had a

'demonstration' and then been expected to follow a set of instructions.

Creating a conceptual understanding of enzymes has been aided by using a large sponge as model of the enzyme amylase and its substrate, starch. The activity of the enzyme at different temperatures is modelled with the tutors (as learners) by simulating these molecules 'crashing' together and by speeding up the reaction with the use of more rapid hand movements. Competitive inhibitors (other pieces of cut sponge which block the active site) and non-competitive inhibitors are also used in this model. After discussion of these concepts with tutors (and the subsequent modifications of the enzyme model), tutors are more confident to reproduce this behaviour with their groups of students.

### Listening to the teaching team

Biggs<sup>9</sup> discusses three levels of approaching teaching practices (in increasing levels of abstraction): 'What students are', 'What teachers do' and 'What students do'. By focussing on the last of these levels, he suggests we can introduce a broad range of 'student-centred' teaching techniques by understanding the student viewpoints or 'misconceptions' as described also by Fensham,<sup>22</sup> Devlin<sup>23</sup> and Schommer.<sup>24</sup>

We have extended these particular ideas of Biggs<sup>9</sup> to our interactions with our teaching teams by asking ourselves 'What do our tutors and demonstrators do?', effectively regarding each team member as a 'learner' (in comparison with Biggs' 'student' or the archaic term 'pupil teacher'). By using this approach as a model of appropriate teaching practice, we can help our teaching teams to view learning from a students' perspective, encouraging them to focus on 'what THEIR students do'.

Once we have asked 'what does our teaching team do?', we need to establish a method for finding out. The chemistry team has been observed in action and have had their strategies reviewed by a professional science educator.<sup>25</sup> Although this is an ideal starting point for any review of pedagogical strategies, it is usually not a practical option. More easily, we can ask the tutors and demonstrators about their teaching experiences and listen honestly to their reflections. When we create a comfortable environment in which each team member feels free to talk about both positive and negative experiences, we notice that the whole team gains renewed enthusiasm about trialling and evaluating novel teaching techniques.

In order to effectively plan such discussions, it is valuable to determine the common concerns of tutors and demonstrators. We have compiled and categorised some of their comments over several years from a range of Universities. Many casual tertiary teaching staff:

- prefer to attempt the class exercises themselves rather than receive sets of 'standard answers', (although they appreciate a chance to ask questions prior to the lab class or tutorial),
  - *it is necessary to ensure that 'everyone knows the right answer', however pre-prepared answers are **not** always be needed, nor desired, nor do they necessarily ensure*

*that everyone understands the concepts behind any particular exercise;*

- need to know the accepted procedures to follow if students are misbehaving, not following instructions or are thought to be engaged in plagiarism;
- need to be aware of the professional action to take if another staff member is thought to be in error in some way;
- are concerned about various aspects of marking and assessment, and require open and transparent guidelines for ensuring consistency,
  - *they also need feedback and encouragement equally as much as the students do;*
- are required to give student feedback **on time** (particularly if students have strict deadlines); HOWEVER ...
  - *...they also need all deadlines and duties to be communicated to **them** in a timely fashion;*
- become very frustrated when they see the **same mistakes** or inadequacies reproduced in exactly the same format year after year,
  - *their 'on the spot' experience can be valuable in updating and correcting our teaching materials*
- value the interactions with technical staff – who are integral members of our teaching teams;
- appreciate any available teaching development or orientation program. Surveys from a range of half- or one-day orientation programs indicate that new tutors and demonstrators value:
  - *hearing experienced tutors' viewpoints and experiences;*
  - *meetings in which everyone is encouraged to give opinions and express concerns;*
  - *networking with other demonstrators (including those from different disciplines);*
  - *discussing a range of different professional ideas on handling potential problems (particularly with respect to 'difficult' students);*
  - *encouragement by supervisors to use their own experience to build confidence in developing teaching strategies;*
  - *definition of the authority they actually have (or don't have) when in the class;*
  - *suggestions and guidelines on writing a reflective teaching journal.*

Gaining some understanding of what our teaching teams may be concerned about has helped us to ensure that we actively listen to their comments and honestly take their ideas into account when planning new strategies. Two examples of how laboratory procedures evolved as a result of changes made due to continual feedback are described.

After many trials of a diverse range of practices, the chemistry team has reached a compromise on pre-laboratory work that is grounded in suitable pedagogy and is also acceptable to both students and demonstrators.<sup>26</sup> We now encompass a range of simple strategies: a published set of questions to help guide students through the forthcoming lab exercise (formative assessment); an in-lab quiz comprising very few of these questions (summative assessment), and a range of conceptual questions that students need to discuss with a demonstrator before proceeding (mastery items).

All our team members have been involved in the preparation and design of a group exercise in which students construct their own models, from scrap materials, of one aspect of protein synthesis and of DNA. Students subsequently give a presentation using these models to illustrate the 3-dimensional and dynamic nature of the molecular processes involved. Due to the collaborative way in which this exercise has been developed,<sup>27</sup> demonstrators have established 'ownership' of the whole process, resulting in a more complex array of student-demonstrator interactions than is usually observed in the laboratory. There is always an audible buzz as students design and handle their models and, as the exercise proceeds, they gradually articulate more sophisticated responses to demonstrators' questions about their conceptual understanding (including discussion of the 'shortfalls' of their particular model).

#### **Have we inspired our tutors and demonstrators?**

How do we know if we have been effective in helping our teaching team to use their own experiences to improve the learning environment for our students? Strict use of 'controls' is not possible in this type of educational research because several 'variables' are being changed all at once as the whole teaching team regularly changes teaching strategies (including 'content') in response to regular feedback from students and from each other. Some ways that indicate that we have been evolving an improved learning community, are described.

Gradually, over the years since 1996 when we have been teaching similar groups of students taking similar units, we have observed the following changes in the behaviour of our students and teaching teams:

- Demonstrators now spend more time closely involved with students in every laboratory session. Even though demonstrators in the chemistry classes wear coloured lab coats, they are difficult to find because they are **always** surrounded by a cloud of white-coated students;
- There is a higher level of pedagogical discussion among teaching team members, as observed by (a) comparing year-on-year minutes of regular meetings; and (b) listening to our own tutors in comparison with other academic staff during workshops or meetings;
- Students engage in a wider variety of 'independent learning' strategies, as noted in tutorials and in comments made on the www-bulletin boards;
- Students have gradually become more willing to discuss their misconceptions and write answers 'in their own words' within their laboratory reports and summative assessments. There is now less concern than formerly with 'following the recipe' to get the practical exercise done 'as soon as possible';
- Collaborative problem-solving strategies have been increasingly used by students within tutorials, and there has been a corresponding decrease in demands for the 'quick' or 'definitive' answers;
- Inhibitions are abandoned more often as students and teaching team members **enthusiastically** use strategies such as games, role-playing and model making;
- Demonstrators, tutors and supervisors have become more reflective practitioners able to critique their pedagogical practices and strategies.

We have also conducted a range of student and peer evaluations, as well as taking account of the students' final grades and results from individual assessment items over several years. The total sum of our responses to feedback from these documents has enabled the continual evolution of our teaching strategies. These feedback items include:

- Peer review surveys (including comments from teaching team members and other academic and technical staff);
- A range of different student evaluation surveys within and between our various units;
- Evaluation surveys from sessional staff commenting on tutor development workshops (that have been facilitated by staff from the Educational Development Centre);
- Year-on-year improvement of students' results in the units 'Introductory Chemistry' and 'Biological Chemistry';
- Favourable comparison of biology students compared with those undertaking the same unit on different campuses.

Although not all the effects noted above can be attributed to the one cause, the compiled responses indicate that we have all been pulling in the same direction to improve the learning environment of our students, and this has been helped by the cohesive and collaborative nature of our teaching teams. At the very least, we have helped to create enthusiastic teaching teams and enjoyable learning environments.

### Summary

By modelling effective teaching strategies and creating a 'safe' environment for sharing of team members' ideas, we have helped our teaching teams to be flexible in creating a collegiate teaching/learning community with their students, which in turn has resulted in a more effective student-centred learning environment.

You may like to try a similar approach with your own teaching teams. We feel we would not have developed such a supportive learning environment if we had taken a more formalised route to 'training' of tutors and demonstrators, such as marking off a 'check-list' to monitor their 'performance'. The only limitations to our strategy are our imagination and willingness to listen and share ideas. One outcome has been the creation of the collaborative discussions we now have with our teams about teaching and learning, and their concomitant development of effective teaching/learning techniques with their students. There is one other important outcome – we have had a lot of fun.

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### Data available...

Details of some of the practices referred to in this paper are available at <http://elearning.uws.edu.au> using Username: **science\_guest** and Password: **guest**

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# Holistic approach to chemical engineering curriculum

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## Abstract

It is often observed that undergraduates have difficulties in making a connection of the subjects they undertake from the beginning to the end of their chosen programmes. Formulating an inter-relational diagram of these subjects can enable undergraduates to make a link between subject and concepts learnt thus giving a good overview. This paper assists the new undergraduates of chemical engineering in formulating integrations, by clearly linking the individual subjects in one simple informative diagram called a spider-web.

## Introduction

The world of chemical engineering is always evolving. Therefore fresh chemical engineering graduates are required to assimilate rapidly to new and emerging technologies, in addition to the existing extensive scope of this field. Thus the correct structuring of the chemical engineering programme is of great importance so that the students become, as they progress through the units, equipped with the right knowledge and tools to face their challenging careers. Generally, the chemical engineering curriculum offers the undergraduate an opportunity to establish a good foundation in science and engineering principles in the sophomore year, followed by two years of fundamental and advanced chemical engineering. The final year concentrates on exposing undergraduates to the application of chemical engineering principles and also an opportunity to stream into their personal choice of elective units.

The objective of this paper is to enable the undergraduates, particularly the first years to understand the significance of each unit undertaken and its contribution towards the whole programme. Often the units are presented in a rather isolated manner, failing to show any sequence from one unit to the other. Failure to recognize these relationships hinders the students from applying interdisciplinary approaches to problem solving, thereby limiting their skills and abilities [1]. This paper therefore looks into a more holistic approach of the chemical engineering curriculum, based upon the syllabus of the Department of Chemical Engineering at Curtin University of Technology. However, the study was only limited to the core units and did not include the elective subjects.

## 2.0 The holistic approach

To understand the contribution of each of the units, a diagram in the form of a spider web (as shown in Figure 1) was created. To simplify the spider web, the curriculum of the programme was divided into four main streams of chemical engineering; Reaction Engineering, Process Engineering, Systems Engineering and Engineering Design and Laboratory. It is stressed here that the units represented in each of these streams are not independent to the courses from other streams, however this is done to simplify the spider web on the basis of the main outcomes and generic attributes of each unit. Horizontally, the spider-

web represents semesters sequentially progressing from first year to the final year, whereas vertically each of the four main streams is represented with the relevant unit belonging to that stream. Main inter-connections of one division to another are also shown to acknowledge these main links. This will enable the student to see the progress they are making in each semester and the continuity of the units already undertaken with the up-coming ones in a systematic way.

The generic attributes of each of these units are obtained from the latest accreditation documents of Curtin University of Technology [2], which is updated every five years. This document defines the target generic attributes for an engineering graduate and judgement on the means that is actually employed to develop and measure these attributes. Further reference on the outcomes and information on the individual units was made in the Units Details of the accreditation documents and related books and journals to assist in generating this spider web. To further understand how the curriculum was streamed into four parts, each of them will be explained here to enable the undergraduates to comprehend the spider-web diagram thoroughly.

## 2.1 Reaction Engineering (Kinetics)

Reaction Engineering involves the principle function of establishing the chemical mechanism of a reaction by correlating equations and data to assist in designing of reactors and specifying operating conditions and control methods [3]. The fundamentals of this division, such as knowledge in general chemistry, thermodynamics and reactions are covered in two separate Chemistry courses that are spread out in the first year. These units are aimed at providing a solid knowledge base of chemical principles, which will serve as a foundation to deal with more advanced and specific chemistry-related problems [4]. Thermodynamics that is taught in the second year of the program exposes students to the significance of thermodynamic analysis in chemical processes using the thermodynamic laws, evaluating thermodynamic equilibrium for multi-phase systems with or without chemical reactions and analysing the performance of heat engines and refrigerators. Physical Chemistry is another branch of chemistry that is offered in the following semester to introduce students to the importance of

electrochemistry and surface chemistry and its application. The final unit in this division is the Reaction Engineering that provides an understanding of basic chemical kinetics and its application in different types of reactors, for example homogeneous, heterogeneous or catalytic reactors.

### 2.2 Process Engineering (Unit Operations)

The processes in chemical engineering can be broken down into a series of steps, called operations, which have its individual techniques based on principles of chemical engineering. Unit operations are largely used to conduct the primary physical steps of preparing the reactants, separating and purifying the products, recycling unconverted reactants and controlling the energy transfer into or out of chemical reactors [5]. In the spider web, the process engineering division is separated into three subdivisions: mass transfer, heat transfer and fluid mechanics. Its foundation is laid out through two courses introduced in the first year; Chemical Engineering & Society and Process Principles. The former unit exposes undergraduates to the nature of work and responsibilities of a chemical engineer to the society and the environment. The latter unit goes into the details of quantitative analysis of chemical processes flow sheets through material and energy balances.

Mass Transfer Operations equips the student with knowledge needed on theoretical and practical aspects of separation processes, including the basic mass transfer concepts and design concepts. The Process Heat Transfer division looks at heat transfer in chemical process systems. This includes problem solving through analytical and numerical methods and also analysis and design of heat transfer equipment. This course provides some of the concepts needed for the connecting unit of Transport Phenomena that taps into the principles and mechanisms of momentum, energy and mass transfer. The theory involved in mass and heat transfer is then applied for the Advanced Separation Processes unit that provides the understanding of equilibrium-staged processes for multi-component distillation, adsorption and ion exchange in application and design.

### 2.3 Systems Engineering (Analysis & Synthesis)

Units in Systems Engineering are concerned with the development and tools to address the generic manufacturing problems of design, operation and control for the process industries [6]. The motivation for these unit is to help students to acquire a 'systems approach' to engineering problem solving and develop skills to tackle complex engineering problems. Generally, this division of Chemical Engineering is separated into two main subdivisions; process control and process analysis and synthesis. For the division of Process Control, two preliminary units are introduced to expose the students to computer knowledge: Introduction to Communication Skills and Programming in Basic. The prerequisite in process control that is Process Instrumentation provides students with knowledge on measurement and

instrumentation for main process variables with selected on-line analysers. Process Control provides the understanding and modelling of the transient behaviour of dynamic systems with introduction to the theory and practise of automatic and feedback control systems while the Advanced Process Control unit that is offered in the fourth year takes a look into advanced chemical process systems, multi-loop and digital control systems.

Units in process analysis and synthesis pull together knowledge of science and engineering for application to a practical design problem. It requires a strong grounding in Mathematics, which is covered in two parts during the first year. Process Analysis provides the foundation of this division as it looks into the application of statistical techniques for chemical process data using numerical techniques. Students will also learn to develop simple experimental designs and concurrently learn to analyse the quality and suitability of their design. This knowledge is further examined in the Process System Analysis unit. The concluding unit in this division, Process Design and Synthesis provides the mathematical and computational techniques required in designing, such as flowsheeting, simulation and optimisation principles [7].

### 2.4 Engineering Design and Laboratory

Chemical engineering design involves activities such as process synthesis and evaluation that include technical, economical, safety and environmental constraints; process selection and design based on mass, heat and momentum transfer; process control, instrumentation and operation; selection of equipment, construction materials, utility requirement, etc [8]. Many units are involved in providing the skills necessary for engineering design. Engineering Mechanics provides students with methods to determine solutions of a range of problems using principles of statics and dynamics. The unit also discusses analysis of structures to determine specifications for safe design and is a prerequisite for the Engineering Materials unit. The later unit offers an understanding of the basis of materials structure and mechanical properties such as range and types of engineering materials, their properties and use, material standards, fabrication and application of construction materials in engineering structures.

The Process Plant Engineering is the key unit for engineering design. Its contents include analysing flowsheets to construct engineering drawings, familiarization with engineering standards, materials specification and selection. Additional knowledge for design is covered in two other units: Risk Management and Process Economics and Management. The former subject enables candidates to appreciate the inter-relationship between occupational health, plant safety and environmental protection, methods to assess plant safety and familiarization with plant operation legislation. Process Economics and Management goes into the important and practical knowledge needed for senior undergraduates who will be starting their careers soon. The contents of this course provide necessary information

about the chemical industry such as market assessment, project management and planning, safety and health management. The Design Project can be described as the backbone of chemical engineering curriculum, as the unit aims to show final year students how chemical and process engineers perform a conceptual design and techno-economical analysis for a plant [9].

Both Chemical Engineering Laboratory units are provided to train undergraduates in the skills of data collection, results assessment and reporting by integrating theoretical knowledge obtained in Fluid Mechanics, Thermodynamics and Heat Transfer in laboratory projects. Together with that, students will also gain experience in safe working methods when using the apparatus and substances required. Process Laboratory Projects on the other hand are project-based laboratory units with emphasis on the design and development of individual projects with introduction to practical experimental design and development. These units are the tools required by undergraduates when faced with their individual Research Projects. In the Research Project units, the student is assigned a project involving the investigation of some aspect of a chemical process using computer or laboratory studies.

### 3.0 Weightage of Streams

All the four streams indicated in the spider-web are vital in the chemical engineering syllabus. However, each stream contains different total number of units and each with its individual credit points (See Figure 1) Engineering Design and Laboratory contributes to the largest credit weightage (one third of overall credits). This is partly also due to the Design Project unit, that covers half of the required credits for the final semester. The other streams that are Process, Systems and Reaction Engineering contribute to 26.7 %, 25.0 % and 15.0 % of the overall credits respectively, indicating that more emphasis is given to the application of chemical engineering in design and system engineering in comparison to the theoretical courses.

### 4.0 Unit Information and Concepts

Besides, the four streams shown in the spider-web, the spider-web also illustrates the units offered on the basis of its main subjects of engineering education. The five main subjects of engineering education include Basic Science and Mathematics, Chemical Engineering Core: Fundamental and Advanced, Computer and Instrumentation and finally Engineering Design and Laboratory.

The purpose of displaying these subjects in the spider web (see Figure 1) is to highlight to the students the nature of the units. Although they do not show an interconnection between the units, it will however benefit the students to comprehend the background or origin of these units. These five branches are also presented in Table 1: *Subjects Areas in Engineering Education*. To obtain further details on unit information and outline, the reader can refer to the Curtin University Online Handbook for Chemical Engineers website at <http://www.curtin.edu.au/curtin/handbook/>. By

relating course outlines to the main streams and engineering education subject areas, the students are able to integrate and extrapolate skills and knowledge obtained from different units.

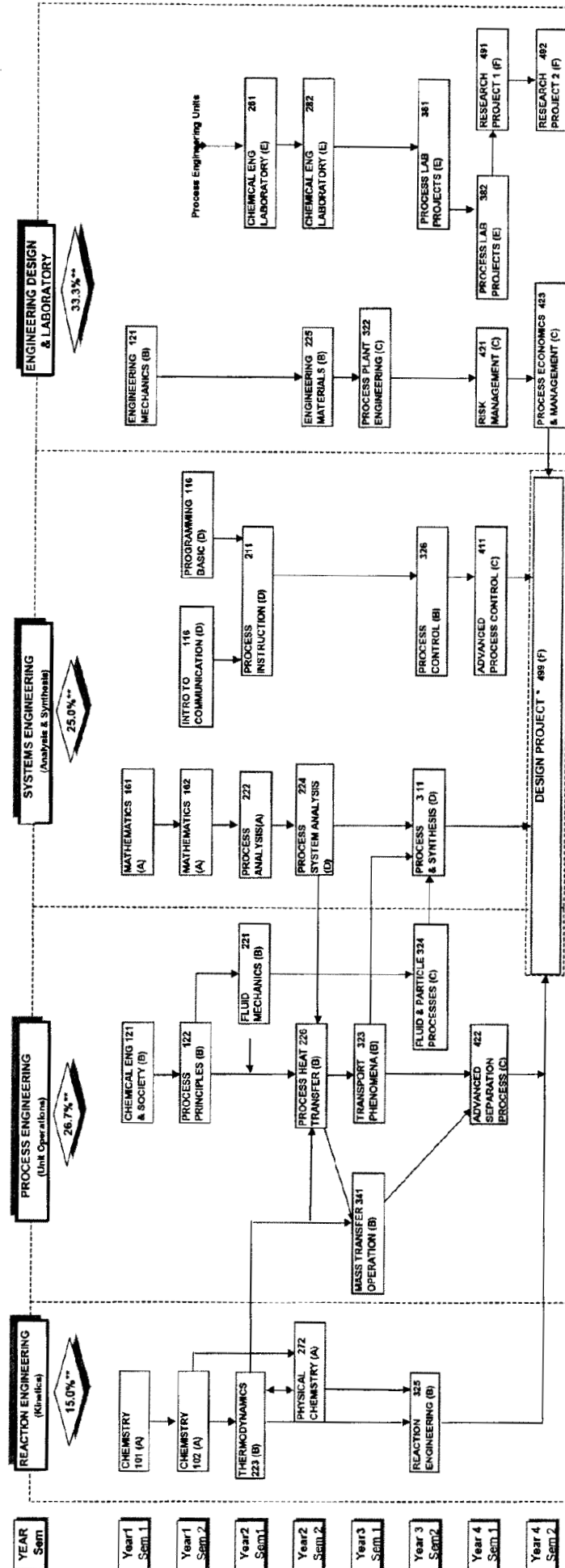
### Conclusion

The objective of the Chemical Engineering IEAUST re-accreditation document clearly states that the Chemical Engineering curriculum has been prepared to produce professional and competent chemical engineers. However, as the curriculum has a wide scope, it is vital that students be exposed to the curriculum in a very systematic and integrated way. Therefore it is essential that the undergraduates, especially the sophomore year students, be guided with a tool such as this spider web to enable them to understand the journey they will be taking. The spider web will also be a good check point for them to reflect on the concepts and skills they have learnt throughout their programme so that they will be able to apply the knowledge learned in relating units that they face in their senior years. This will help emerge and refine their problem solving skills, which is a vital asset of confident chemical engineers.

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Figure 1: Spider Web - Holistic Approach to Chemical Engineering Curriculum


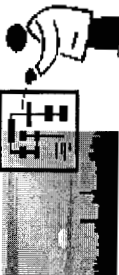

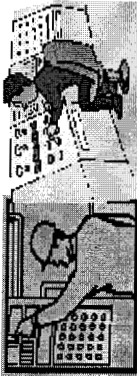



Subject Areas of Engineering

A	Basic Science and Mathematics
B	Chemical Engineering Fundamentals
C	Chemical Engineering Advanced
D	Computer and Instrumentation
E	Laboratory
F	Project

Note \* Design Project although shown separately, is included under Design Engineering.  
 \*\* The weightage of each of the streams are in terms of the total unit credits

Table 1: Subjects Areas in Engineering Education

SUBJECT AREAS IN ENGINEERING	UNITS OFFERED			
	YEAR 1	YEAR 2	YEAR 3	YEAR 4
<b>Basic Science and Mathematics</b> 	Chemistry 101 Chemistry 102 Mathematics 161 Mathematics 162	Process Analysis Physical Chemistry		
<b>Chemical Engineering Core: Fundamentals</b> 	Chemical Eng & Society Process Principles Engineering Mechanics	Thermodynamics Engineering Materials Process Heat Transfer Fluid Mechanics	Mass Transfer Transport Phenomena Reaction Engineering Process Control	
<b>Chemical Engineering Core: Advanced</b> 			Fluid and Particle Processes Plant Engineering	Advanced Separation Advanced Process Control Risk Management Process Econs & Management
<b>Computer and Instrumentation</b> 	Intro to Communication Skills Programming in Basic	Process Instrumentation Process System Analysis	Process Design & Synthesis	
<b>Engineering Design and Laboratory</b> 		Chemical Eng Laboratory 1 Chemical Eng Laboratory 2	Process Laboratory Projects	Process Laboratory Projects Research Project Design Project

# The emission spectroscopy of $C_2$ produced in a hydrocarbon/oxygen flame: An APCELL experiment<sup>1</sup>

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## Introduction

Small hydrocarbon radicals are important as intermediates in combustion processes, including the disposal of household and chemical waste by incineration, in engines, and in energy generation. Moreover, their introduction into the environment plays a significant role in atmospheric chemistry. During combustion, of the more abundantly produced hydrocarbon radicals,  $C_2$  is a species that can be readily generated in a simple natural gas/oxygen flame and is amenable to study at the undergraduate level. Its bright emission allows for ready spectral identification with equipment commonly found in most undergraduate laboratories. By monitoring the production of  $C_2$  in various regions of a flame, students can begin to explore the chemistry of combustion. In addition, by recording and analysing the electronic emission spectrum of  $C_2$ , students can gain insight into the structure and bonding of a radical molecule, which is quite different to stable molecules most usually encountered in the undergraduate laboratory.

In this experiment, students begin by observing the emission spectra of atomic species generated in relatively intense discharge lamps prior to studying  $C_2$  molecular emission from a flame. As such, they become familiar with data collection and interpretation strategies in a relatively straightforward manner. Having mastered these skills, students have the competence and confidence to record molecular emission spectra of less luminous species present in a flame. During a one-afternoon laboratory session, the normal expectation is that students will record the emission spectrum of  $C_2$ . Students subsequently perform spectral analyses to determine molecular constants in various vibronic states of the radical and use these results to gain insight into the nature of the chemical bond (*i.e.* changes in bond length upon electronic excitation). Noting the relative abundance of  $C_2$  in various regions of the flame also provides students with insight into the chemistry of the combustion process.

Important aims of this exercise are to reinforce (i) the notion of quantised energy levels in atoms (electronic) and molecules (rotational, vibrational and electronic,) and (ii) the spectroscopic concept of transitions occurring between these levels. Students also develop competency in recording and interpreting emission spectra as well as developing generic skills associated with graphical and mathematical analysis (particularly non-linear least squares fitting), self-evaluation of results and critical thinking.

## Educational Template

### Section 1 - Summary of the Experiment

#### 1.1 Experiment Title

The Emission Spectroscopy of  $C_2$  Produced in a Hydrocarbon/Oxygen Flame.

#### 1.2 Description of the Experiment

Spectroscopy provides a means to examine places and things that are not readily accessible. For example, spectroscopy is the tool with which we can determine the composition of stars. It also tells us which species in Earth's atmosphere protect us from UV radiation, or contribute to the greenhouse effect. Spectroscopy also provides us a window to examine the microscopic world of atoms and molecules. Measurement of spectra and knowledge of spectroscopic theory provides us with the ability to determine the shape and size of molecules, the bonds that hold them together and their reactivity. In this experiment students use spectroscopy to examine both of these applications: they measure the free radical species present in a flame and use this information to enquire into the chemistry of combustion. Detailed analysis of the  $C_2$  spectrum by the students, using quantum theory that is taught in most undergraduate physical chemistry syllabi, allows the structure and bonding of this free radical to be inferred.

In this experiment, the electronic emission spectra of small, diatomic, radicals produced in a hydrocarbon/oxygen flame are recorded and the  $C_2$  spectrum is analysed. The experiment begins by having the students observe the emission spectra of atomic species generated in relatively intense discharge lamps. In this way, they become familiar with data collection and interpretation strategies in a relatively straightforward manner. They then move on to study emission spectra of less luminous species present in a flame where they identify common radical species such as  $C_2$ , CH and/or OH.

The experiment is designed to be run in one afternoon (4-6 hours) for Level II or Level III undergraduates (depending upon individual curriculum requirements).

The aims of the practical are:

1. To develop competency in the measurement of emission spectra;
2. To measure and record the discrete molecular transitions in  $C_2$ , CH and OH from a mixed

<sup>1</sup> The complete documentation for this experiment is freely available on the APCELL web site [www.apcell.org]. It includes the educational template, a set of student notes, demonstrator notes and technical notes to allow ready implementation into a new laboratory.

- hydrocarbon/oxygen flame;
3. To explore the chemistry by which these species are produced;
  4. To analyse the spectrum of  $C_2$  in terms of quantum theory of electrons and vibrations of a diatomic molecule;
  5. To use the parameters of the analysis to provide the force constant of  $C_2$  in both ground and excited state, and hence infer the bond order of  $C_2$  in each state;
  6. To relate the bond order of  $C_2$  to theories of bonding, e.g. molecular orbital theory, valence bond theory.

### 1.3 Course Context and Students' Required Knowledge and Skills

The experiment develops practical skills related to the underlying principles of atomic and molecular spectroscopy that is presented in most second and third year lecture courses and extends the application of these principles to combustion chemistry. Students should have a basic knowledge of quantised energy levels in atoms (electronic) and molecules (rotational, vibrational and electronic). Ideally, students should also have an understanding of the spectroscopic concepts of transitions between these levels and the relationship with the electromagnetic spectrum. However, this is not considered essential as students can learn these concepts as part of the experiment.

### 1.4 Time Required to Complete

Prior to Lab	1 hour
In Laboratory	4-6 hours
After Laboratory	1-2 hour

### 1.5 Acknowledgments

The experiment has evolved over several years at Adelaide, Sydney and Griffith Universities. Professor A. E. W. Knight at Griffith University implemented the earliest incarnations of the experiment that we are aware of in the early 1980's. The Submitters, at Adelaide and Sydney Universities, have jointly developed more recent modifications and refinements over the last five years.

### 1.6 Other Comments

#### **Times Required:**

The practical involves background reading in order to answer preliminary questions. The required apparatus has been set-up in advance for immediate data collection during laboratory time. Spectral analysis and subsequent interpretation of results with respect to combustion chemistry is also performed during laboratory time. Students are required to write their practical report outside of the formal laboratory session.

#### **Equipment and apparatus required:**

This experiment can be established using equipment commonly found in most physical chemistry laboratories, including:

- Na, H and D discharge lamps;
- Methane/Oxygen flame source, e.g. Bunsen burner or preferably a glassblowers torch;
- Dark room (Optional. This experiment has been

performed successfully in a fully lit laboratory.)

#### **To observe emission spectra:**

- Hand-held spectroscope;
- Bench-top spectroscope.

*To record emission spectra (if required, for example, if a bench-top spectroscope is not available. The accompanying student notes refer to the use of a bench-top spectroscope.):*

- Various quartz focusing lenses;
- Dispersing monochromator (e.g. f/10) with photomultiplier tube (or a dispersing CCD system);
- Power supply for photomultiplier tube (e.g. Fluke 4128);
- Signal amplifier or Picoammeter (we use a Kiethley 410A picoammeter).
- A means of displaying spectrum. This could be:
  - Chart recorder, but it then is more difficult to compare simulated spectra;
  - Computer with D/A converter;
  - Data logger (with computer to upload data);
  - Digital oscilloscope connected to computer (e.g. GPIB) with appropriate software.

(We have used a chart recorder, digital scope and D/A converter, which all do the job just fine. We plan to test data loggers because students often have experience with these, even from high school).

#### **To analyse spectra:**

- Scientific data analysis/graphical packages (e.g. Excel and Kaleidagraph or Origin)

#### **Safety aspects:**

The flame is hot. If used in an enclosed space (e.g. dark room) the fumes should be removed via an appropriate exhaust fan. High voltages (~2000 V) are also used to drive the photomultiplier tube, if used.

#### **References:**

Good reference books include:

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5. "The Spectroscopy of Flames" A. G. Gaydon (Wiley, 1957).
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The technical reference sections of product catalogs published by optics manufacturers, including Newport, Oriel, Melles Griot, etc, are of tremendous use.

## Section 2 – Educational Analysis

<b>Learning Outcomes</b> <i>What will students learn?</i>	<b>Process</b> <i>How will students learn it?</i>	<b>Assessment</b> <i>How will staff know students have learnt it?</i> <i>How will students know they have learnt it?</i>
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**Theoretical and Conceptual Knowledge**

The students will use theoretical aspects of spectroscopy taught in lectures to analyse spectra, extract molecular constants, calculate molecular properties, compare them with literature values and interpret the results	Students in pairs or small groups perform data analysis, with occasional guidance provided by a demonstrator. Comparison with literature results will allow the students to self-evaluate their spectral analyses.	During the experiment, interaction with a demonstrator will indicate that students are proceeding on the right path. Students are expected to write and submit a report detailing the results of their data analyses, including a discussion of a comparison with literature values.
Students will gain insight into the chemistry of combustion processes occurring in a simple hydrocarbon/oxygen flame.	Students will identify radical species produced in various regions of a flame, and discuss possible mechanisms of formation of identified species. Information about flame chemistry is available in the reference material.	During the experiment, the demonstrator will query the students on flame chemistry. In the written report, students will discuss the combustion process. An intelligent mechanism for the production of the observed radical(s) will allow staff to assess the students' understanding of flame chemistry.
The students will make their own inference on the bonding of $C_2$ , which is not intuitively obvious. They will test whether their inference makes sense compared with theories of bonding.	From extraction of the force constants from their own experimental data, the students can infer the bond order of $C_2$ in both ground and excited electronic states (both are approx. double bonds). The students should discover that molecular orbital theory, in fact, predicts not only a double bond for $C_2$ in both states, but that both states should be triplets (which is information the students are given).	The demonstrator should query the student about the value of their calculated force constants. During the laboratory hours the demonstrator should also check that the students remember at least that molecular orbital theory exists! The answers to the discussion questions concerning bonding in the practical should be written up in the report.

**Scientific and Practical Skills**

Experimentally, students will learn the procedure and aspects of observing emission spectra.	Student pairs perform the experiment with occasional guidance provided by a demonstrator. When they observe discrete atomic lines from the discharge lamps they will know, themselves, that they have mastered this technique.	The successful observation of spectral transitions will be the indication that the students have mastered the necessary observation skills required of this experiment.
Students will learn to assign a spectrum, by indicating the emitting species and also the quantum levels involved in the emission.	Assignment of the spectrum is done by reference to the literature.	Correct assignment of the spectrum is integral to the successful completion of the prac. Students are specifically requested to confirm their assignments with a demonstrator before progressing. In this way they will get immediate feedback on the skills in assigning a previously unknown spectrum.

Students will gain proficiency in non-linear least squares fitting of their experimental data to a fairly complicated 5-parameter model.	Students will use Microsoft Excel (or any other appropriate software) to perform a non-linear least squares fit. Successful extraction of the 5 molecular parameters will provide immediate feedback that they have mastered this skill.	Successful extraction of the 5 molecular parameters.
Students will learn to question what the numerical value of their results means in terms of fundamental chemical ideas. Specifically, in this experiment they infer a bond order and then question whether this bond order seems sensible.	By employing one or more theories of bonding, the students can examine whether their numerical values make sense in terms. Specifically, molecular orbital theory provides a bond order with which they can rationalise their own inferences.	Correct application of m.o. theory and more importantly being able to connect the ideas of m.o. theory to their own experiment.

### Generic Skills

The ability to work in a group and coordinate activities will be one of the key generic skills learnt.	Group members are required to divide up tasks in a fair, equitable and transparent manner.	The demonstrator's interaction with the students will allow their progress to be effectively gauged. Peer and demonstrator evaluation will assess this component of the practical exercise.
The ability to compare results with literature values and to reflect upon the significance of these results.	Discussion with a demonstrator is vital to encourage the students to think about their results and what they mean.	Student discussion and evaluation (oral and/or written) of the quality of their data will indicate their level of understanding.
Students will enhance effective communication by having to submit a written report.	Written communication skills will be developed as the report is prepared.	The required written report will evaluate this aspect.

## Section 3 – Student Learning Experience

### 3.1 Did this experiment help you to understand the theory and concepts of the topic? If so, how, or if not, why not?

- S1: Yes, application of theory learnt in lectures.  
 S2: No. Covered these principles before and I understood them.  
 S3: Yes. We get to observe the flames by ourselves and then extract the data and then manipulate them.  
 S4: At the start it didn't but then I got the background and it started to make sense.  
 S5: Yes, made understanding the parameters clearer.  
 S6: At then end of the course, I finally do.  
 S7: In terms of the background theory, not really because we did the experiment before the lectures but I did learn that the different bands responded to different transitions of vibrational states.  
 S8: The presence of the vibrational parameters were not completely explained, ie we did not know what each parameter meant.  
 S9: Yes, it demonstrated vibrational energy levels and how to determine the energy of the states.

### 3.2 How is this experiment relevant to you in terms of your interests and goals?

- S1: N/A.  
 S2: Not relevant.

- S3: Quite relevant.  
 S4: Do the experiment. Get the degree. Helped in making a decision with Honours.  
 S5: Increased my interest in the topic.  
 S6: Not more than any other.  
 S7: Not really relevant since I am not going to pursue this for a job in the future.  
 S8: Not very relevant as flame emission is quite a basic experiment.  
 S9: I found it interesting but it isn't relevant theory wise.

### 3.3 Did you find this experiment interesting? If so, what aspects of this experiment did you find of interesting? If not, why not?

- S1: Not really.  
 S2: Yes. Using the hand held spectroscope was fun.  
 S3: Yes, quite interesting.  
 S4: Yes – refer to 3.9  
 S5: Yes, actual hands-on experience.  
 S6: Yes – visual. That always helps.  
 S7: The hand-held spectroscopes were a waste of time but the actual flame emission part was quite interesting.  
 S8: The function of the telescope was quite interesting.  
 S9: Simply finding out how much energy is required to excite a molecule vibrationally was interesting.

**3.4 Can the experiment be completed comfortably in the allocated time? Is there time to reflect on the tasks while performing them?**

- S1: Yes.  
 S2: Yes.  
 S3: No. Need more time (6 hours).  
 S4: Yeah, very easy.  
 S5: Yes.  
 S6: Yes.  
 S7: If you are the second group yes, but the first group not really as you have to do all the little things to the spectrometer to see the bands clearly and this takes quite a lot of time.  
 S8: Plenty of time.  
 S9: If work is completed efficiently the time was enough but if the task is found to be hard to understand there may not be enough time.

**3.5 Does this experiment require teamwork and if so, in what way? Was this aspect of the experiment beneficial?**

- S1: Yes, to try and get the equipment to work.  
 S2: Yes. Trying to work out how to actually work the bench top spectrometer and checking bands with each other.  
 S3: Yes.  
 S4: Yes – Laurence & I work well as a team.  
 S5: Yes, a scribe & someone to find the lines.  
 S6: Teamwork is always good – but if you have Grant in your group there isn't as much teamwork.  
 S7: Yes, so one can use the spectrometer & the other take the results.  
 S8: No, the experiment could quite easily be done by one person. The only teamwork needed is to collaborate results.  
 S9: Yes, someone to record the wavelengths & someone to measure using the spectrometer.

**3.6 Did you have the opportunity to take responsibility for your own learning, and to be active as learners?**

- S1: Yes.  
 S2: No.  
 S3: Yes.  
 S4: Had to. Demonstrator wasn't here all the time. Made me do it & then understand it.  
 S5: Yes.  
 S6: Yes.  
 S7: Yes, as not much help was given by demonstrators as they were busy so had to take it upon yourself to understand what was going on.  
 S8: Yes!  
 S9: Yes.

**3.7 Does this experiment provide for the possibility of a range of student abilities and interests? If so, how?**

- S1: No comment.  
 S2: No  
 S3: Yes, the ability to extract data and manipulate them.  
 S4: It shows chemistry isn't just making & destroying

molecules.

- S5: Yes.  
 S6: It's something different.  
 S7: No comment.  
 S8: Not as such. The chemistry is quite simple and not very broad.  
 S9: It requires understanding of theories before the calculations can be completed. Thus, for those who have trouble with the theory will have trouble with the calc's.

**3.8 Did the laboratory notes, demonstrators' guidance and any other resources help you in learning from this experiment? If so, how?**

- S1: Yes, the notes explained the theory.  
 S2: No.  
 S3: Yes, they do because they help us to understand the theory.  
 S4: When a demonstrator isn't there the notes are hard to understand.  
 S5: Yes – how to work the equipment.  
 S6: No comment.  
 S7: Yes they were quite clear but the notes on how to use the spectrometer could have been a little more clearer.  
 S8: Yes, to determine the values of the vibrational parameters.  
 S9: Yes, learning how to use equipment provided a different explanation to the lab manual.

**3.9 Are there any other features of this experiment that made it a particularly good or bad learning experience for you?**

- S1: No comment.  
 S2: No.  
 S3: They're all good learning experiences. Extract data then manipulate them to get important parameters.  
 S4: It was good just to see something different, eg. Colours in the fluoro etc.  
 S5: No comment.  
 S6: No.  
 S7: No, not really besides slightly burning myself.  
 S8: The hand-held spectrometer was very inaccurate as the wavelength changed as the spectrometer moved around.  
 S9: No comment.

**3.10 What improvements could be made to this experiment?**

- S1: No comment.  
 S2: ?  
 S3: Longer time (say, 6 hours).  
 S4: No comment.  
 S5: Maybe try more than one molecule.  
 S6: No comment.  
 S7: Get rid of the hand-held spectroscopy part.  
 S8: Make the equipment a little more user friendly.  
 S9: Not using the hand-held spectrometer!

**3.11 Other Comments**

No comment from any of the students.

# Determination of silver by differential pulse anodic stripping voltammetry: An APCELL experiment.<sup>1</sup>

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## Introduction

There are a number of sensitive and accurate analytical techniques that can be used to detect metal ions in water samples, for example, Inductively Coupled Plasma (ICP) [1] and Atomic Absorption Spectroscopy (AAS) [1]. However, those methods require the use of highly expensive instrumentation, can only be used in a laboratory with gas (eg. acetylene) access and be operated by a trained technician or chemist and most importantly they cannot speciate, ie. it is not possible to determine whether for example, As(III) or As(V) ions are present in the sample. Speciation of metal ions is required for understanding the role trace metals play in natural waters and the effect on human health. Voltammetry is another analytical method which is used in trace metal analysis [2]. It is just as sensitive as ICP and AAS [1], however, it is considerably less expensive in terms of instrument cost and set-up, can be used in field and most importantly has the advantage of species characterization, ie. possible to determine the exact chemical nature of the trace constituent. There are a number of different voltametric techniques; however the most widely used for trace metal analysis is Anodic Stripping Voltammetry (ASV). ASV is an electrochemical technique in which the current-potential behaviour is measured and it basically consists of two-steps; deposition and stripping. In the deposition step, metal ions from the solution are reduced at a negative potential and are deposited onto an electrode. Then the potential is gradually made more positive and the metal is oxidised or stripped back into solution generating a current which is proportional to the concentration of metal ions in solution for a given deposition time. The ASV instrument is very simple it consists of a cell where the sample is placed, a stirrer and three electrodes; working electrode, where at which the reaction of interest occurs, the reference electrode, which provides a known and steady potential and an auxiliary or counter electrode, which minimizes errors from cell resistance in controlling the potential of the working electrode. There are a number of different working electrodes which can be used, such as hanging mercury drop electrode (HMDE), thin film mercury electrode (TFME) and composite carbon electrode. The accuracy and reproducibility of ASV is highly dependent on the quality of the surface of the electrode, because of this HMDE has the advantage over the other two electrodes

since a new mercury drop is generated for each run. However, composite carbon electrodes provide an extended anodic potential range, which means they can be used for a wider range of metals. In addition, carbon electrodes are safer to use than HMDE and allow for the system to be used in field. Composite electrodes combine the advantages of micro-electrodes (e.g. analysis of small samples volumes, ability to work in highly resistive solutions) with much higher currents due to larger surface areas.

In this experiment students will investigate some aspects of ASV using carbon electrode to detect silver ion concentration in water samples. The exercise also encourages students to consider such issues as accuracy of different analytical techniques, relative costs, availability, etc.

## Acknowledgements

The authors wish to thank members of the APCELL team for the help in running this experiment at the APCELL Workshop. Dr. Michael Ridd from James Cook University for his encouraging and helpful discussions at the APCELL Workshop. Big thank you must also go to third year chemistry students at ECU for performing the experiment and providing valuable feedback and suggestions, especially Paul Lewtas, finally to the APCELL referees for their comments and suggested improvements.

## Educational Template

### Section 1 - Summary of the Experiment

#### 1.1 Experiment Title

Determination of Silver By Differential Pulse Anodic Stripping Voltammetry.

#### 1.2 Description of the Experiment

Detection of trace amounts (down to ppb levels) of metal ions, especially heavy metal ions, in drinking water is of great importance due to health reasons [1]. It is now well known that metals such as lead, mercury, cadmium and arsenic are toxic even at very small concentrations [1], because they accumulate in vital organs in our bodies and can cause cancer and other health problems.

Anodic Stripping Voltammetry is the most sensitive electro-analytical technique currently available for the

<sup>1</sup> The complete documentation for this experiment is freely available on the APCELL web site [[www.apcell.org](http://www.apcell.org)]. It includes the educational template, a set of student notes, demonstrator notes and technical notes to allow ready implementation into a new laboratory.

detection of trace amounts of electro-active metal ions. Understanding the principles of voltammetry and acquiring skills in being able to use ASV to detect species of interest in a given water sample is the goal of this experiment.

In this exercise students will use ASV to determine concentration of silver ions in a given water sample. As part of the experiment students will gain better understanding of the ASV method by investigating the effect of accumulation or deposition time, performing chemical pre-treatment on the working electrode, analysing samples which contain two metal ions with similar stripping potentials, determining the difference in accuracy between two calibration methods and finally analysing a given water sample containing unknown quantity of silver ions.

### 1.3 Course Context and Students' Required Knowledge and Skills

This experiment forms part of a Bachelor of Technology (Applied and Analytical Chemistry) degree at Edith Cowan University. As part of their degree students enrol in Analytical Chemistry II unit, which is run in the first semester of the third year of that degree. The course focuses on the theory and application of analytical methods with an emphasis in the laboratory on experiments with a 'real world' component, a problem which they are likely to encounter in industry.

Most of the students enrolled in this unit are also concurrently completing a second unit which covers other analytical techniques, such as Atomic Absorption Spectrophotometry. This enables the students to consider how analytical techniques complement each other and the limitations and appropriateness of each technique in different sample analyses.

The students have already covered electrochemistry and polarography theory in previous year in a Physical Chemistry unit and they have completed one polarography experiment using hanging mercury electrode. Current experiment introduces students to a new technique called 'Anodic Stripping Voltammetry'. Instead of using a

hanging mercury electrode, a composite carbon electrode is used. The metal ions in the solution are electro-reduced onto the carbon electrode and then are stripped away by reversing the voltage. This experiment emphasises the application of this technique and investigation of some basic voltammetry concepts rather than getting students to perform another routine 'theory heavy' voltammetry laboratory.

The experiment assumes that students have the following skills and knowledge:

- Basic knowledge of polarography
- Basic understanding of the principles of voltammetry
- Ability to prepare standard solutions
- Skills in the use of automatic pipettes
- Understanding of the two types of calibration methods
- Ability to construct calibration curves and calculate standard deviations
- Completion of practicals; 'Atomic Absorption Spectroscopy' and 'Polarography'

### 1.4 Time Required to Complete

Prior to Lab	1 hour reading
In Laboratory	2-3 hours "wet" laboratory
After Laboratory	2-3 hour report writing

### 1.5 Providence

The original source of this experiment is unknown. It was adopted from a third year Analytical Chemistry 2 laboratory manual at ECU put together by Dr Jackie Rummey. There are however, many similar experiments which use ASV to determine various metal species in water samples, see for example those published in *J. Chem. Ed.* [3-6].

### 1.6 Other Comments

This exercise can be easily adopted for analysis of other metals such as zinc, cadmium, lead, mercury, arsenic etc., and is relatively cheap in terms of chemical cost. Portable voltammeters are now available for around \$5000.

## Section 2 – Educational Analysis

Learning Outcomes	Process	Assessment
<i>What will students learn?</i>	<i>How will students learn it?</i>	<i>How will staff know students have learnt it?</i> <i>How will students know they have learnt it?</i>

### Theoretical and Conceptual Knowledge

Students will gain a better understanding of some simple voltammetric concepts, such as deposition time.	For example, students will perform a number of runs on a silver standard of certain concentration and investigate the effect of changing deposition time.	Demonstrator will probe students for discussion during experiment and ask questions with regard to their results. Students are also expected to write and submit an 8-10 page scientific report where they will have to answer questions on their results, which the demonstrator will mark and return to students with comments.
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<p>Students will use theoretical aspects of analytical chemistry and voltammetry to analyse the given samples. For example, theoretically students know that a calibration curve is needed to determine concentration of an unknown solution, but how is this achieved practically?</p>	<p>The analysis is expected to be performed independently (or in pairs) with occasional guidance provided by a demonstrator. Students will perform “dummy runs” of the samples, and compare them against a known standard in order to determine the range of standards needed for calibration. They will then use the calibration data to determine concentration of the given unknown sample.</p>	<p>Interaction with a demonstrator will indicate that students are following the right path. If they do not select their standards appropriately then the unknown sample value will lie outside the calibration range. Students will submit a scientific report detailing the results of their data analyses. Demonstrator will mark the report commenting on the quality of student’s data with respect to the unknown sample. The unknown sample would have been previously analysed by the lab technician.</p>
<p>Students will use theory to explain the difference between standard addition and external standard calibration methods.</p>	<p>Students will determine concentration of the given unknown water sample using two types of calibration methods.</p>	<p>Demonstrator will probe students to comment on the accuracy of the two calibration methods prior to analysis and justify their answer with theoretical explanation. Students will report their results in the scientific write-up and discuss their findings in terms of whether their results reflect what they would have expected.</p>
<p>Students will be able to apply the concept of metal-chelate complexation to eliminate interfering metal ions in the ASV technique.</p>	<p>As part of further investigation students will be asked to add some copper standard to a silver standard solution and they will discover that the copper peak overlaps with the silver peak. They will then add EDTA to the solution to complex copper and then re-run the solution to see the effect of EDTA (ie. only single peak due to silver should be seen).</p>	<p>Students will be asked to answer questions explaining the effect of the EDTA and to comment on their results. All voltammograms will be submitted in the report for marking.</p>

**Scientific and Practical Skills**

<p>Experimentally students will learn how to use the GAT voltammeter. Specifically, they will learn how to correctly set-up all electrodes and how to set-up the GAT software with parameters such as; deposition, strip and clean potentials, accumulation, strip and clean time and chemical pre-condition.</p>	<p>The analysis is expected to be performed independently (or in pairs) with occasional guidance provided by a demonstrator. Student will successfully perform runs on standard samples and obtain peak heights which correctly reflect the concentration of silver ions in the standard solutions.</p>	<p>Demonstrator will monitor student’s progress during the laboratory session. If there are any problems with running the voltammeter demonstrator will probe student for possible explanation and guide the student to help him/her to come up with a solution. In addition students will be probed by the demonstrator to explain certain aspects of the voltammeter and how it works. Plus show that they know how to set up the GAT software for different types of runs, eg. if they wanted to analyse different metal ions.</p>
<p>Students will gain further practical skills in standard preparation and the correct use of automatic pipettes.</p>	<p>Students will be asked to prepare all standard solutions themselves and the quality of their results should reflect the accuracy of their analytical skills.</p>	<p>Demonstrator will monitor student’s use of automatic pipettes and standard solution preparation during the laboratory session. Students will be marked on the quality of their results.</p>

Students will learn how to use “dummy runs” to select and make up standards in the correct range for calibration.	Students will be given a sample with an unknown silver ion concentration and will need to determine the concentration of this sample using calibration curve. They will first need to work out the range of standards needed for the unknown sample by firstly performing some ‘dummy runs’. This will guide them in terms of what standards they will need to prepare so that the unknown sample is within the standard range.	The successful arrival at the correct concentration (as previously determined by lab technician) of silver in the unknown sample will indicate that students have been successful in the use of the ‘dummy runs’ in choosing the correct standard range.
Students will learn how to be proficient with a scientific data analysis/graphical package.	Students will use the GAT program to analyse their data and plot calibration curves using both the external standard method and standard addition method. Hence they will obtain result for their unknown silver solution.	Demonstrator will monitor student’s progress in the use of GAT software during the laboratory session. Students will be asked to submit all plots generated by the GAT software.

### Generic Skills

Critical analysis of why one particular analytical technique is chosen over another.	Discussion with a demonstrator is vital to encourage the students to think about their results and what they mean. The guidelines for writing the report also pose some questions to encourage students to make comparisons between analytical techniques.	The demonstrator’s interaction with the students will allow their progress in the laboratory to be effectively gauged. The required written report will also provide evaluation.
Students will develop new and industry relevant computer skills.	Students will use a software driven voltammeter to set-up runs and to analyse their data.	Students will demonstrate familiarity with computer driven voltammeter and be able to use the software to different types of analyses.
Students will further practice written communication skills by having to submit an 8-10 page scientific report	Students will be asked to prepare a detailed, clear, well-structured formal scientific report.	The report will be marked according to criteria given in experimental notes and students will receive written feedback from the demonstrator commenting on the report.
If done in pairs, students will further develop cooperative skills in a team environment and learn how to coordinate activities.	When working in pairs students will need to divide the tasks between themselves ensuring equality in workload and access to instrument.	Demonstrator will observe that both students are engaged in most aspects of the experiment and that they both have had enough practice using the instrument by asking each student to demonstrate how to use the software.
Students will further develop their mathematical skills in working out standard concentrations and dilutions using ppb units for concentration.	Students will need to prepare all standard solutions themselves and use $c_1V_1 = c_2V_2$ to work out different concentrations of standard solutions in the electrochemical cell.	Students will be asked to show all calculations within their final report as marks will be given for all working out. Demonstrator will provide feedback for incorrect calculations.

### Section 3 – Student Learning Experience

#### *Explanatory notes to Student Learning Experience*

The version of the experiment presented here and the associated documentation have all been revised incorporating suggestions from the APCELL workshop participants, APCELL referees and student responses.

#### **3.1 Did this experiment help you to understand the theory and concepts of the topic? If so, how, or if not, why not?**

S1: Yes, voltammetry was a bit of a puzzle. After the experiment, my understanding of the theory increased.

S2: Yes, it confirmed what I thought.

S3: Yes, the effect of accumulation time is investigated so we see that an increased time gives a larger peak. Also seeing the effect of EDTA and the difference between a calibration curve and standard additions.

**3.2 How is this experiment relevant to you in terms of your interests and goals?**

S1: N/A.

S2: It demonstrates how voltammetry is another analytical method which I may one day need to use in a job.

S3: It is relevant to the electrochemistry theory given to us in Analytical Chemistry 2 unit.

**3.3 Did you find this experiment interesting? If so, what aspects of this experiment did you find of interesting? If not, why not?**

S1: Yes. We got to know the advantages and disadvantages of using EDTA.

S2: Yes, the interesting parts of this experiment in the 'what ifs'. Getting errors and finding how to fix them is the good stuff. Running standards or even unknowns is easy but the investigation is very important.

S3: Yes, it is set-up in an investigative manner.

**3.4 Can the experiment be completed comfortably in the allocated time? Is there time to reflect on the tasks while performing them?**

S1: No. I suppose so.

S2: No, due to the fact that standards need to be repeated. It can be a pain.

S3: Time is an issue, maybe it should be two labs one as an introduction/investigation, ie. accumulation time/EDTA and a second as analysis of unknown and application of previous.

**3.5 Does this experiment require teamwork and if so, in what way? Was this aspect of the experiment beneficial?**

S1: Yes, students can do different tasks, ie. prepare sample, etc. and save time. Yes.

S2: Yes, conformation among others helps. Group thought processes are very important for this lab.

S3: Yes, as there are often several things to be done at once between scans so to get things done more efficiently.

**3.6 Did you have the opportunity to take responsibility for your own learning, and to be active as learners?**

S1: Yes, developing ideas.

S2: Yes, running our own theories and practicing our ideas. From thought out method and trial and error, our own results are well designed.

S3: Yes, as we explored the experiment we had opportunities to discuss what is happening and why.

**3.7 Does this experiment provide for the possibility of a range of student abilities and interests? If so, how?**

S1: Yes, if they are interested in voltammetry. Also it is fun.

S2: For some students electrochemistry and voltammetry maybe right up their alley. Exposure to this method is valuable.

S3: Yes, because there are different jobs which need to be done; ie. computer operator, making solutions, analysis.

**3.8 Did the laboratory notes, demonstrators' guidance and any other resources help you in learning from this experiment? If so, how?**

S1: Yes, having the voltammogram from the demonstrator helps in knowing what is expected.

S2: Yes, guidance was the most help. The notes were useful where applicable. Changes needed to be made on the day. Experiments are not expected to be perfect on the day.

S3: Yes, both the notes and the demonstrator. When we were unclear with the notes the demonstrator explained.

**3.9 Are there any other features of this experiment that made it a particularly good or bad learning experience for you?**

S1: Some of the solutions were old. The program used needs to be changed. It plays tricks!

S2: The errors are a good thing. Errors help in the understanding of the procedure. By correcting them, the theory becomes clearer.

S3: Being like an investigation makes it a powerful learning experience as it provides a proof for the theory.

**3.10 What improvements could be made to this experiment?**

S1: A new computer with another program would make the experiment more successful. Ways of getting reproducibility and limit of tasks to be done.

S2: Less work, that is, less standard additions or normal calibration. This is to save time.

S3: Need a section to show the reproducibility of scans and make the experiment into two parts.

**3.11 Other Comments**

S1:

S2: Mock examples are good, because we have little exposure to voltammetry so we don't know where to expect a peak. Questions 1 to 4 are very good, but by now 5 and 6 should be known.

S3: Having sample results is good because it gives some idea of what is expected.

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