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

AusJEC reference styles are based on the most recent edition of the Publication Manual of the American Psychological Association OR the Journal of Chemical Education.

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In this issue ..........

Four of the published papers were presented at the RACI Chemical Education conference in Hobart in February 2004. In the first of these de Jong describes a study into views of the education research-practice gap. Participants in the study were asked their opinion on the reasons for this gap and for possible actions to bridge the gap. One factor behind the gap was a need to survive. For teachers, this stems from insufficient time to read the research literature or to apply research findings. For the researcher, there is the need to publish in high impact journals and present at research conferences, neither reaching many teachers. Also, both teachers and researchers had unrealistic expectations of each other. Improving the communication between researchers and teachers was the focus of suggestions for bridging the gap. These included actions for teachers and researchers.

Beasley presents a paper on teacher reactions to radical curriculum change. This change requires a shift in pedagogy from a “concept to exercises” approach to a “context to concept” approach. The paper analyses the challenges facing teachers and students in schools throughout Queensland and reports on their experiences and expectations after one year of a two-year trial period.

Both de Berg and Rae present papers dealing with the historic development of chemical ideas. de Berg describes how pedagogical history can be used to teach the key chemical concept of ions in solution. Pedagogical history is the integration of history of science with information relating to the teaching and learning of the topic from the literature. In this teaching/learning module, an introduction into the dissolution process is followed by analysis of Raoult’s experimental evidence and the development of theories to explain these observations. Debate and conflict among scientists are also presented. Students involved in the first draft unanimously indicated an overall favourable impression. In the second chemical history paper, Rae describes the contribution of two scientists, Josef Loschmidt and William Sutherland, in the understanding of chemical bonding. Loschmidt proposed a new method for the representation of structures of organic molecules, including a cyclic structure for benzene (years before Kekulé). In Sutherland’s study of liquid water, he proposed that it consisted of an equilibrium mixture of dimer and trimer and that the bonding involved positive and negative electrons.

Sotheeswaran provides a personal perspective on chemical education gained from 35 years of teaching. He describes how the University of the South Pacific has embraced the opportunities offered by the technology age and adapted to the “student of today”.

From the APECELL series, Lim, describes an IR experiment to investigate the bonding in carbon monoxide. Determination of the bond order will allow the determination of the direction of the molecular dipole in CO. The dipole direction has important implications in understanding how CO acts as a poisonous gas or as a ligand in metal complexes. As usual in the APECELL series, there is an educational analysis of the exercise, including consideration of theoretical and conceptual knowledge, scientific and practical skills, and generic skills.

Finally, Davidowitz reviews the book Prometheans in the lab: Chemistry and the making of the modern world, authored by Sharon Bertisch McGrayne (McGraw-Hill, 2001) and Mitchell presents another interesting discussion in his column The Word on Chemistry.

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Editorial - The (non) perception of chemistry as human activity

Is chemistry about substances, their reactions and structures? Or is it about people making observations and interpretations about substances, their reactions and structures - and using and making them? Surely it is the latter – as implied by definitions that begin “Chemistry is the study of ………………….” Who does this study? People, of course!

Let’s start from that basis. Then it is pertinent to ask whether the chemistry that is presented to our students, both secondary and tertiary, reflects the discipline as a human activity. Secondly, does the chemistry that we present reflect a current activity? Thirdly (in response to an implied negative reply to the previous questions) do these issues have a bearing on enrolments in chemistry courses?

There is a research study crying out to be conducted. It consists of surveys to see if there is a difference between students’ perceptions of chemistry and the biological sciences in terms of current human activities. I have a hypothesis that the answer is related to the bulging classes in biology that we have seen over the last twenty years. It is plain that the biological sciences are selling themselves through the underlying themes of what people are doing to try to cure cancers and AIDS, to understand genetic disposition to certain diseases, and to develop methods for use in criminal forensics, for example, while chemistry that is presented at lower levels is about what the likes of Dalton, Lavoisier and Schrodinger did (You surely noted the past tense?)? Of course we in the field know that chemistry is undergoing enormous unfolding of knowledge, much of it related to the fields listed above that have been designated biological sciences. But are these advances, and the urgency of them, translated to our teaching? Well let’s examine this issue.

It seems that every general chemistry undergraduate text has a blurb early on about the nature of science. Presumably the authors are trying to make the message about chemistry as a human activity. Inspect some of them and look at not only what they say, but how they say it. So much is conveyed (or not conveyed) in the language style. Here are key excerpts from a Foreword about the nature of science

• The scientific process begins with observations. These are normally made on controlled conditions in the laboratory.
• Observations may be qualitative or quantitative.
• Careful examination of scientific data sometimes reveals similarities, regularities or patterns which can be concisely summarised by a generalisation.
• Proposed rationalisations of observed phenomena are called theories or, if tentative, hypotheses.
• Theories are the keys to scientific progress. Each is an attempt to explain observed behaviour in terms of a model.
• The real power of a theory is its ability to suggest properties that have not yet been observed.

Such passive language! Where are the people!? We have observations and rationalisations being made by nobody it seems. And theories seem to be a force in their own right, independently of persons! ‘The real power of a theory is its ability to suggest …..’! Hands up all of you who have heard a theory suggest anything. [Yes, I know that you know what the sentence means, but your understanding is not the issue here.]

Okay, let’s move beyond the foreword, and inspect the language of discussion of ideas in the body of the text. For example, common to any number of texts: A pure substance is a single substance with a fixed, characteristic composition and a unique set of properties. This, and hundreds of other definitions contain not even an implication that we talking of a human construct, or using a ‘man-made’ language label. There is a suggestion that the concept of pure substance is somehow an absolute truth, defined by a greater power. Might we use something like this instead: If we obtain evidence that a certain stuff is composed of only one substance, we call it pure. Simple re-wording, but powerful differences in the message.

Or, as an introduction to the kinetic molecular theory:

We might ask why the volume of a gas sample is inversely proportional to its pressure at a given temperature, or why each gas in a mixture exerts a partial pressure independently of the other gases. Answers to these questions are provided by kinetic molecular theory.

Models in themselves do not give answers to any questions! But people use models to account for observed properties.

Pedantic, you think? Well language is very powerful. Let’s take a step further. Imagine that tomorrow a radiation bomb wiped out every human being on earth. Would there still be d orbitals? Would there still be hybridisation? Would there still be standard reduction potentials? Would there still be hard and soft acids? Would perhaps a newly arriving, curious life form perhaps begin to rationalise the world through different perspectives? Now look at your textbooks, and your lecture notes, and judge if these concepts are presented as ways of thinking by people, or as some absolutes that operate without human interaction.

Apart from the language and style of expression, what about the content? Although at lower levels of education there is a move towards learning in student-related contexts, most high school and lower undergraduate courses (those which the general masses have opportunities to participate) are built around the structure that expert chemists believe will provide a foundation for those who go on to specialise: stoichiometry, oxidation and reduction, atomic structure, bonding, acids and bases, and so on.

From a historical perspective, where does a student come to realise that after Dalton the keenest minds on earth argued for 60 or 70 years the validity of a particulate view of matter? It is all disguised in one sentence: “All matter consists of atoms.” Such a mis-representation! Perhaps it is supplemented by a ‘throw-away’ half page and a

*to continue on page 9*
Mind your step: bridging the research – practice gap

Onno De Jong

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Abstract

Teachers and researchers complain about a gap between chemistry (or broader: science) education research and the implementation of research findings in the teaching practice. The present article deals with a small-scale empirical study into views on this gap, especially views on explanations for the gap and views on actions for bridging the gap. These views are discussed by presenting several realistic measures, at a personal level and at a structural level, for establishing closer links between research and teaching practice.

Introduction

Research in chemistry education is a rather young branch on the tree of human knowledge, much younger than research in modern chemistry that started about two centuries ago (Lavoisier, Proust, Dalton). However, the origin of chemistry education research can be located halfway in the last century, so, about 150 years later. The rise of chemistry education research has strongly been influenced by large-scale science curriculum reform in the USA, initiated in the late 1950s, and the UK, initiated in the early 1960s. Prominent chemistry curricula for secondary schools were the North-American projects of Chemical Education Materials Study (CHEM Study) and the Chemical Bond Approach (CBA), and the British project of Nuffield Chemistry. The reform was mainly guided by curriculum concerns and courses were designed to represent more adequately the ‘body of knowledge’ of chemistry in terms of basic chemistry concepts and rules (instead of a large number of chemistry facts). For that reason, the materials were developed by broad teams of leading chemists and chemistry educators, advised by specialists from other educational areas, such as the psychology of learning. The new curricula were based on shared expertise and opinions regarding chemistry education, but chemistry education research was lacking, for the simple reason that this research did not exist at that time. It came up through the curriculum reform because there was increasing interest in gathering evidence to establish the effects of the new curricula on students’ knowledge and performance.

The further development of chemistry education research has been stimulated by a new wave of curriculum reform since the 1980s, for instance, the British Salters Chemistry project, and the North-American project of Chemistry in the Community (ChemCom). In the context of this reform, the design of chemistry courses was much more guided by concerns for the learner and how what is learned may contribute to effective citizenship. New themes entered chemistry education research, for instance, chemistry students’ alternative conceptions and ways of reasoning, and the learning of chemistry concepts in contexts. Interest in the chemistry teacher also came up, especially his or her (initial) knowledge and beliefs of how to teach chemistry topics and issues.

The main goal of research in chemistry education, like research in chemistry, is the building of knowledge. This knowledge can be generated regardless of whether the knowledge is of immediate usefulness. But it can also be generated because of the primary goal of the applicability. The present article deals with the ‘applied’ perspective by addressing the relationship between chemistry education research and teaching practice. This relationship is problematic. For many years, researchers have pointed out the poor effects of their efforts, for example, they complain that the outcomes of research often do not find their ways into the practice of teaching of chemistry and other natural sciences (Shymansky & Kyle, 1992). On the other hand, practising science teachers consider personal experiences, common sense, and official documents as much more important sources of their professional knowledge than results of research (Costa, Marques & Kempa, 2000). In conclusion, a gap between chemistry (or more general: science) education research and teaching practice can be indicated. When addressing this issue for tertiary chemistry education, Coll and Taylor (2003) even used the term parallel universes for indicating the gap.

In the present article, a small-scale empirical study into views on explanations for the research-practice gap is reported. After a discussion of these views, a small-scale study of views on actions for bridging the gap is also reported. These views are discussed by presenting several realistic measures, at a personal level and at a structural level, for establishing closer links between research and teaching practice. In this article, a sharp distinction between (research in) chemistry education and science education will not be made. Although the article mainly covers secondary education level, most of the content can be extrapolated towards tertiary level.

Views on explanations for the research-practice gap

In 2002, I conducted a small-scale study into views on the research-practice gap. The participants in this study were a group of 64 South African graduate students and university staff members. All of them had experience with teaching science at secondary schools or universities, and/or teaching science education at teacher training colleges or university departments, and were familiar with science education research. From this broad experience, they acknowledged the presence of the gap. In the first part of
the study, the participants were asked individually to write down the most important explanations for the gap between science education research and teaching practice.

Their answers were collected and analysed from an interpretative phenomenological perspective (Smith, 1995), without the use of an a priori established system of categories or codes. Instead, categories were developed on the basis of the data, through an iterative process during which the data were constantly compared with each other. As a result, the answers were classified into three main categories: (a) personal reasons, expressed from the teacher perspective, (b) personal reasons, expressed from the researcher perspective, and (c) structural reasons, expressed from the common perspective. Each of these categories consisted of several sub categories. All participants gave at least two classified different answers. An overview of the results is given in Table 1.

The results show that most of the statements regard ‘teacher’ reasons, followed by ‘researcher’ reasons, and structural reasons. Regarding the personal reasons, most statements refer to a lack of knowledge or skills. Illustrative statements from the teacher perspective are:

“Teachers do not know what research has been done” (category 1.2)

and

“Teachers are unable to implement ideas from research” (category 1.3).

Illustrative statements from the researcher perspective are:

“Researchers use language that is often complex – a simple idea is dressed up to seem difficult” (category 2.1)

and

“Researchers do not have a clue what is going on in the class, and what the problems are” (category 2.2).

Regarding the structural reasons, an illustrative statement is:

“Much science education research is disseminated via journals and conferences that teachers do not read or attend” (category 3.1).

Although the present study is small-scaled, the results cover a wide range of explanations that support findings and views from elsewhere (cf. Costa et al. 2000; Hurd, 1991; White, 1998). The reported personal reasons can be explained from several factors behind them. Some of them are presented below.

First of all, teachers and researchers feel a need to survive. Teachers cannot find enough time to read research articles because they are already too busy with their existing teaching. Even if they have time for reading, they need extra time for translate and integrate the content into their teaching practice. Researchers also have to survive, which means that they have to publish in high-ranked journals read by only a few teachers. Of course, some of them publish in journals for teachers, but that does not provide rewards in terms of ‘research’ output.

Secondly, another explanatory factor behind the reported ones might be the differences in the way in which researchers and practitioners view each other. Teachers might be inclined to think that research ought to provide them with solutions for their teaching difficulties. Researchers might be inclined to believe that teachers are able to transform the reported research outcomes into useful ideas for teaching. Unfortunately, from both sides, the expectations are too high and the views are not very realistic.

The participants have also reported some structural reasons. These can also be explained from factors behind them. In my opinion, one of the most important structural factors is about the impact of leading theories of teaching and learning. This issue is concisely addressed in the next section.

### Table 1. Explanations for the research-practice gap, reported by 64 respondents

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<thead>
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<th>Category</th>
<th>Number of statements</th>
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</thead>
<tbody>
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<td>1. Personal reasons: the teacher perspective (71)</td>
<td></td>
</tr>
<tr>
<td>1.1 Not enough time for reading research literature</td>
<td>19</td>
</tr>
<tr>
<td>1.2 Little knowledge of research outcomes</td>
<td>17</td>
</tr>
<tr>
<td>1.3 Unable to apply research implications</td>
<td>15</td>
</tr>
<tr>
<td>1.4 Weak belief in usefulness of research</td>
<td>11</td>
</tr>
<tr>
<td>1.5 Fear for consequences of proposed changes</td>
<td>9</td>
</tr>
<tr>
<td>2. Personal reasons: the researcher perspective (49)</td>
<td></td>
</tr>
<tr>
<td>2.1 Unable to give clear recommendations</td>
<td>18</td>
</tr>
<tr>
<td>2.2 Little knowledge of teaching problems</td>
<td>13</td>
</tr>
<tr>
<td>2.3 Strong belief in their own ‘ivory tower’</td>
<td>11</td>
</tr>
<tr>
<td>2.4 Preference for addressing general issues</td>
<td>7</td>
</tr>
<tr>
<td>3. Structural reasons: the common perspective (34)</td>
<td></td>
</tr>
<tr>
<td>3.1 Little communication between researchers and teachers</td>
<td>23</td>
</tr>
<tr>
<td>3.2 Little collaboration between researchers and teachers</td>
<td>11</td>
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</table>

### Influences of theories of teaching and learning

Over the past several decades, the (theoretical) framework of chemistry education research is strongly influenced by cognitive theories of teaching and learning (as the successor of behaviouristic theories). In the beginning, these theories stimulated a rise of the research interest in chemistry courses, based, for example, on theories of conditions of learning (Gagne, 1965), or theories of guided discovery learning (Bruner, 1975). Many studies on these courses were mainly focused on learning outcomes and did not explore the interaction of instruction and learning. Many research data were obtained by using multiple-choice questions and other quantitative methods (cf. Nurrenberg & Robinson, 1994).

In my opinion, the value of the mentioned cognitive theories for improving chemistry education is restricted. The conclusions of research that has been carried out in the context of such theories tend to be too general to be helpful for designing courses in specific chemistry topics. For example, it is possible to develop several diverging courses from one and the same cognitive theory. The reverse way is also possible: one specific course can be based on different cognitive theories. In other words, there
is no close relationship between these cognitive theories and specific education practices. Many studies have focused on aspects of teaching and learning that are essentially ‘content-free’ and refer to general problems. However, most chemistry teachers are faced with content-related difficulties in teaching and learning. They want to understand the reasons why these specific problems arise.

In sum, as long as chemistry education research generates outcomes in terms of general conclusions and implications, many teachers will be disappointed, and the gap between research and practice remains.

During the last decade, there has been increased interest in studies of the teaching and learning of specific chemistry topics. This issue-specific research is strongly stimulated by the current leading theory of knowledge acquisition: constructivism. According to this perspective (see e.g. Driver, 1989), learning is a dynamic and social process in which learners actively construct meaning from their actual experiences in connection with their prior understandings and the social setting. A major implication for chemistry teachers is the idea that they should have an insight into students’ (authentic) conceptions and ways of reasoning with respect to chemistry topics. Many issue-specific studies are focused on students’ difficulties in understanding specific chemistry concepts and rules. A database of these studies is developed by Anderson and McKenzie (2002), and can be found on the website: www.card.unp.ac.za. Many studies involve qualitative methods for collecting data, for example, by recording interviews, think-aloud monologues (Bowen, 1994), or classroom discussions (De Jong, 1995).

In my opinion, issue-specific research is an important tool for improving chemistry education. However, its value depends on the nature of the chosen research instruments. Records of interviews and think-aloud monologues can be used before or after classroom instructions, but they are not very fruitful for investigating the teaching and learning of chemistry as it actually takes place in the classroom. For that kind of research, it is particularly useful to produce records of discussions between students and their teachers in educational situations. Moreover, these records can also be used to analyse specific chemistry teachers’ conceptions and actions. However, studies that include data about classroom discussions and other teaching and learning activities are rather scarce. In sum, chemistry education research that generates issue-specific conclusions and implications can contribute to bridge the research-practice gap. This kind of research is necessary, but it is obvious that this is not sufficient. Other actions for bridging the gap are also needed. Suggestions for these actions are reported in the next section.

**Views on actions for bridging the research-practice gap**

In the second part of the empirical study mentioned before, I have asked the 64 participants individually to write down the most important actions for bridging the research-practice gap. Their answers were collected and analysed in the same way as reported before. As a result of this procedure, the answers were classified into three main categories: (a) ‘teacher’ actions, (b) ‘researcher’ actions, and (c) structural actions. Each of these categories consisted of several sub categories. All participants gave at least one classified answer. An overview of the results is given in Table 2.

The results show that most of the statements regard structural actions, followed by ‘researcher’ actions and ‘teacher’ actions. Regarding the personal actions, illustrative statements are:

“Teachers should develop their own abilities to be able to respond to what is written in the literature” (category 1.1) and

“Researchers should write reports that are teacher friendly, and publish in journals for teachers or informal media like papers and magazines (more accessible)” (category 2.1).

Regarding the structural actions, an illustrative statement is:

“Teachers and researchers come together in workshops, and exchange experiences” (category 3.1).

The recommended actions can be considered as the counterparts of the reported explanations for the research-practice gap. Most of the statements were formulated in a rather concise and general way. For that reason, I will present some elaborations of the proposals in the next sections.

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**Table 2. Actions for bridging the research-practice gap, suggested by 64 respondents**

<table>
<thead>
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<th>Number of statements</th>
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<tbody>
<tr>
<td><strong>1. Personal actions: the teacher perspective</strong></td>
<td>(27)</td>
</tr>
<tr>
<td>1.1 Teachers learn how to handle research literature</td>
<td>17</td>
</tr>
<tr>
<td>1.2 Teachers engage in research activities from time to time</td>
<td>10</td>
</tr>
<tr>
<td><strong>2. Personal actions: the researcher perspective</strong></td>
<td>(29)</td>
</tr>
<tr>
<td>2.1 Researchers learn how to publish in an accessible way</td>
<td>22</td>
</tr>
<tr>
<td>2.2 Researchers engage in teaching activities from time to time</td>
<td>7</td>
</tr>
<tr>
<td><strong>3. Structural actions: the common perspective</strong></td>
<td>(39)</td>
</tr>
<tr>
<td>3.1 More communication between researchers and teachers</td>
<td>28</td>
</tr>
<tr>
<td>3.2 More collaboration between researchers and teachers</td>
<td>11</td>
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**Linking research to practice: the personal level**

From the teacher perspective, two actions were suggested. The first recommendation is about teachers’ learning how to handle research literature. This competence is not easy to acquire, but it can be developed through specific workshops for teachers. In these meetings, they can learn to analyse and discuss the meaning and usefulness of research articles. In my opinion, these articles should be selected carefully to prevent lack of interest, misunderstanding, and feelings of loss of time. An additional measure can be to invite researchers to join the meetings for explicating their publications. This is also a way to enhance the communication between researchers and teachers (see action category 3.1).

The second suggested action is about the engagement of teachers in research activities from time to time. This ‘teacher-as-researcher’ role can vary from the teacher as...
reflective practitioner till the teacher as formal educational researcher. Sweeney, Bula and Cornett (2001) provide a number of specific actions that are summarized as follows. Teachers can keep lesson journals, write essays, and make audio- or video-records of classroom activities for reflecting on their teaching and students’ learning. They can also share their experiences by discussing their documents and records in small group meetings with peers, and, finally, they can write short articles about their research for chemistry teachers’ journals. In my opinion, collecting, analysing, and discussing the findings should be carried out in a rather systematic way to go beyond ‘anecdotal’ views, although sharing of teaching anecdotes can play an important role as an initiator of discussions between teachers. It is obviously that all these actions require the presence of inquiry skills at a certain level. These skills can be developed in teacher preparation and professional development courses that integrate theory with teaching practice.

From the researcher perspective, two other actions were suggested. The first proposal regards researchers’ learning how to publish in an accessible way. Obviously, for many researchers, this competence is not very easy to acquire, but can be learnt in the context of specific writing workshops for researchers. In these meetings, they can learn to write summaries and implications that identify the specific meaning of the findings in daily-life terms for teaching and learning. In my opinion, researchers should be guided to find the right standards by inviting teachers to come to the meetings for giving feedback, and discussing the accessibility of the manuscripts. Beside, this can improve the communication between researchers and teachers.

The second recommended action is about the engagement of researchers in teaching activities from time to time. This ‘researcher-as-teacher’ option does not appear to be very realistic when looking at the poor possibilities to replace teachers for a certain period. An alternative can be to stimulate researchers to contribute to teaching about research at colleges for pre-service teacher training and professional development. In my opinion, this active participation in teaching will be more fruitful when the researchers are guided by professional teacher trainers who can help them to improve their understanding of teaching from a practitioners’ point of view. Beside, in this way, the communication between researchers and teachers can also be enhanced.

**Linking research to practice: the structural level**

Most of the suggested actions refer to improving the communication and collaboration between researchers and teachers. These issues are elaborated by several authors elsewhere (cf. Coll & Taylor, 2003, Gilbert, De Jong, Justi, Treagust & Van Driel, 2002; Hurd, 1991). In the present section, I will elaborate the collaboration between teachers and researchers by concisely presenting an action research approach that is called ‘developmental’ research (Lijnse, 1995). In this approach, a small-scale curriculum development is linked with in-depth research on social, content and context specific teaching and learning processes. The structure of the research involves repeated cycles (a spiral) of activities. This cyclical method includes the following stages. First, the evaluation of current educational situations, for instance, the identification of students’ pre-knowledge and skills. In that stage, analysing existing explorative studies can be useful. Second, in conjunction with reflection on science and science education, research questions are formulated. Third, new teaching strategies and materials are developed and implemented. Fourth, teaching and learning processes are investigated during classroom and laboratory sessions. Important ways of collecting data are audio/video-records of educational activities. Finally, the results are used in a new cycle of research.

Important tools for teaching and investigating are ‘didactical’ scenarios. By the way: the term ‘didactical’ does not refer to the (dominant Anglo-Saxon) meaning of technical education tricks, but to the (dominant Dutch-German) broader meaning of teaching and learning processes. These scenarios can be developed through collaboration between researchers and teachers, and in connection with the development of teaching and learning materials. Lijnse and Klaassen (2004) have described the following functions of ‘didactical’ scenarios. First, describing the expectations of researchers and teachers about the teaching and learning of a particular topic or issue. Second, guiding teachers in what they should do (and why) when teaching. Third, acting as a research instrument when analysing deviations from what was expected (testing hypotheses). Finally, contributing to the construction of well-founded structures for teaching particular topics or issues.

In the area of chemical education, an example of a ‘development’ research project, that includes the use of a ‘didactical’ scenario, is presented by Stolk, Bulte, De Jong and Pilot (2003). Their study deals with a new issue in the Dutch chemistry curriculum, viz. the teaching and learning of chemistry concepts in contexts. Preceding to their project, a teaching-learning module about ‘super absorbents’ was developed by some teacher-designers. By using this module, teachers can help their students to understand, and select, water-absorbing materials for diapers (nappies) and other applications. The chemistry behind this context consisted of basic organic concepts, polymers, and the hydrophilic feature of substances in relation to their molecular structure. The chemistry teachers who were involved in the project joined a course that consisted of college workshops connected with classroom teaching. They discussed the module and formulated expectations for the lessons, recorded their teaching, and, after teaching, they evaluated the module and their classroom activities in terms of deviations from their expectations. The researchers in the project prepared a ‘didactical’ scenario (together with the teachers), observed the lessons, and interviewed the teachers before and after teaching. The findings show a fruitful collaboration between teachers and researchers, especially regarding the clarification of teachers’ conception and performance in the classroom with respect to the new curriculum content. Although the teachers acknowledged
the usefulness of the research activities, most of them indicated to have a lack a clear insight in the underlying goals of the course and the research. The findings were used to revise the module, the ‘didactical’ scenario, and the design of the teacher course for a next cycle of teaching and inquiry.

In conclusion, the present ‘developmental’ research is one of the many faces of action research. This paradigm can contribute to the bridging of the research-practice gap, but it is also obvious that a number of potholes should be filled and pitfalls avoided in order to make the bridge an effective way of bringing research and practice together.

References


Continuation from page 4:

Editorial - The (non) perception of chemistry as human activity

photograph or two. It is worth reading some of the papers of Mansoor Niaz1 from Venezuela who argues for more authentic exposure to the debates of times gone by in the development of our knowledge.

And also as throw-aways, rather than basic foundations, are the discussion of the cutting edges of chemistry advancement, their intent, their potential usefulness, and their human involvement. Difficult? Biologists manage to present difficult stuff to students by highlighting the key features. Why can’t we?

We have been, and are, bound by the use of passive language, and a belief that we need to present chemistry according to an analysis of the logic of the discipline seen from the eyes of the expert chemist. These are not serving us well.

RBB


Continuation from page 19: Kevin C. de Berg

The development and use of a pedagogical history for a key chemical idea: The case of ions in solution

- References -


Teacher reactions to radical curriculum change: The journey to again become expert

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Abstract
The challenge to change classroom practice has always been a tension for science teachers. For Queensland teachers the most radical pedagogical change experienced in their lifetimes is now expected from a new generation of syllabuses for the teaching of senior school physics and chemistry. As always the ideal curriculum (Queensland Syllabus Authority Syllabus, 2001) has expectations beyond the present competence and belief structures of the teachers and the available resources. Essentially the new syllabus requires a 180-degree turn around in pedagogy to make it consistent with a Context to Concept teaching approach. This new model is in sharp contrast with 50 years of Concept to Exercises pedagogy. Associated with such a radical change is a very different balance of student assessment instruments required to meet different syllabus outcomes. The balance is now very much in favour of student investigations (Experimental and Non-Experimental) evolving out of focus questions generated from face to face interactions within the school-generated contexts. This paper analyses the challenges facing chemistry teachers in Queensland and reports on their experiences and expectations after one year of a two-year trial period.

Introduction
The challenge to teach in context and for students subsequently to learn in context is an emerging challenge for science teachers (Lye et al., 2001; Whitelegg et al., 1999). For Queensland teachers, this challenge is immediate. The publication in July 2001 of the Trial-Pilot Syllabuses in Chemistry and Physics by the Queensland Board of Senior Secondary School Studies represents a new dimension in syllabus renewal. This syllabus design stands in stark contrast to the design of the 1995 syllabuses (Beasley, 2001). The paradigm shift underlying this innovation in design requires radical changes in teacher and student actions for the taught, learned and assessed curriculum. A 180-degree change in teacher and student behaviour is necessary for the syllabus to be implemented in the spirit to which it is intended.

Essentially the learning settings will require a change from

A CONCEPT TO EXERCISES APPROACH
(1995 Syllabus)

to

A CONTEXT TO CONCEPT APPROACH
(2001 Draft Syllabus)

Associated with this radical change in pedagogy is a very different balance of student assessment instruments that are required to meet different syllabus outcomes. The balance is now very much in favour of student investigations (Scientific and Non-Scientific) evolving out of focus questions generated from face-to-face interactions with the school-generated contexts. This paper analyses the challenges facing teachers and students in schools throughout Queensland and reports on their experiences and expectations after six months of a two-year trial period.

The meaning of “context”
The 2001 Draft Chemistry Syllabus uses ‘context’ to mean “a group of related situations, phenomena, technological applications and social issues”. Examples of possible contexts as portrayed in the Trial/Pilot syllabus are for chemistry: Drugs, Medicine and People; The Air We Breathe; Fertilisers and Pesticides.


The freedom allowed in the syllabus for teachers in individual schools to choose contexts is spawning a plethora of examples. An initial survey of schools suggests that there is very little overlap in the choice of contexts. This freedom stands in stark contrast to earlier initiatives in other Australian states such as Victoria and New South Wales where external examination requirements did not allow such an open choice (Hart, 1997). Time management and school organisational arrangements constraints indicate that schools would be struggling to implement courses of study around more than six contexts over 2 years.

Underlying assumptions about content of contemporary syllabuses
A syllabus in its broadest sense reflects a hypothesis about learning - what is worth learning as well as how it should be learned and assessed, and as such reflects the deep-seated values and beliefs of the designers. With this particular syllabus one can recognise the following changes in emphases (National Research Council, 1996).

Less emphasis on
Knowing scientific facts and information
Studying subject matter of disciplines
Separating science knowledge science content
Covering many science topics

More emphasis on
Understanding scientific concepts and developing abilities of inquiry
Learning subject matter in the context of inquiry, technology, science in personal and social perspectives, and history and nature of science
Integrating all aspects of and science content
Studying a few fundamental science concepts
Implementing inquiry as a set of processes

Implementing inquiry as instructional strategies, abilities, and ideas to be learned.

Concept-based design (1995 Syllabus)

In this model, science is transmitted to students as discipline-based knowledge that has its worth (for students) in its contribution to a tertiary entrance score. Recent studies into science teaching in Queensland report that “teacher talk” remains the dominant teaching strategy (Goodrum et al, 2001). Transmission of scientific knowledge devoid of a meaningful framework of student experience or prior knowledge is the predominant teacher behaviour. Such a model of science teaching has resulted in the application of scientific theory as an optional infrequent experience for students. When a context is introduced it is often done superficially through exercises and usually occurs at the end of an instructional sequence if time, interest or teacher knowledge permit.

This model of teaching in chemistry classrooms can be illustrated as follows:

Figure 1. A model of teacher transmission of content in science classrooms

Context-based design (2001 Syllabus)

The starting point for the design of units of work by schools is the selection of an appropriate context. This context and the concept map surrounding it are expected to lead to meaningful questions that will focus student investigations and other learning experiences in the unit. This school-based decision is only constrained by teacher interest and expertise, access to resources for investigations, the conceptual underpinning of the context, and the time required.

The syllabus requires that a number of key concepts be visited on at least two occasions during the investigations of the chosen contexts. The design encourages teachers and students to develop an understanding of these key concepts on a ‘need-to-know’ basis. The context as initially revealed at the beginning of a unit remains central to the classroom processes and specific conceptual development becomes important when student uncertainty hinders further elucidation of meaningful knowledge and skills.

These elements in the chemistry syllabus are connected in the manner represented in Figure 2 (Queensland Studies Authority, 2001).

A context

allows development of ...

key concepts

which are arranged in ...

themes

and are developed through the use of

key ideas and other ideas

Figure 2. The relationship between the elements of a unit of work.

This approach requires teachers to engage students in authentic real-world experiences of the context as the starting point for student learning (Anthony et al, 1998). In doing so the model requires that initially the context be elaborated by building up a concept map about the context. At the centre of this map is the context surrounded by a circle of issues, features or events associated with the context. Further out, the associated science processes, models, topics, and science concepts are represented. This is all surrounded by a representation of the community and school resources which could/need to be accessed in order for students to investigate a choice of questions which arose from the issues raised earlier in the initial elaboration of the context.

The following flowchart (Figure 3) outlines the major steps in the design of a unit of work commencing with the context being revealed, through to the finalisation of learning as evidenced in student presentations and reports (Butler, & Beasley, 2002)

Comparison of the learning sequences diagrammed in Figures 1 & 3, soon reveals that a radical change in classroom pedagogy is required. The challenges for both teachers and students to act differently are substantial and will require a period of sustained professional development opportunities. This perspective contrasts markedly with the type of assistance that is made available to Trial/Pilot schools by the QSA. The Authority’s professional development workshops are only concerned with the generation of an acceptable school work program (Accreditation) and with the awarding of appropriate Levels of Achievement (Certification) of student performance.
The teaching/learning journey for teachers and students in chemistry is illustrated in Figure 4 below.

The context which has been chosen has been McChemistry (Niethe, 2002). In this Unit of Work, students will study the nutritional value of McDonald's food as well as its chemical composition. The journey to teach/learn in context commences at the centre of the figure where the “context” is explored and explained. This analysis leads to a number of questions about the chemistry of the food products marketed to prospective consumers. These questions represent a number of inquiries which could be pursued through scientific investigation by groups of chemistry students in senior high school classrooms.

The outer circle represents the knowledge inventory which forms the concepts which “needed to be known” in order to investigate the chosen research questions.
Learning to perform: novice to expert models

The professional development of trial teachers and students requires the management of progression through diverse stages of growth. Dreyfus and Benner (1984) provide an insightful and useful research-based framework that describes the attributes of professional behaviour associated with five stages of professional growth from ‘novice to expert’.

These stages are continuous and are labelled accordingly:

Stage 1: Novice - Rule governed behaviour
Stage 2: Advanced Beginner - Believing someone knows the answer
Stage 3: Competent - Being strongly analytic
Stage 4: Proficient - Synthesising performance
Stage 5: Expert - Tacit knowledge

The trial teachers and students are ‘novices’ in the enactment of context-based syllabuses. Consequently the required professional development of the teachers and the students comes down to managing the progression through these higher stages. This progression is not more of the same at each stage. It is four essential transformations of the basis of their practice. It means that professional development requires specific interventions at the different stages. It means that an understanding of which stage one is at can lead to what the self needs to grow strongly.

Not everyone will make the whole journey. Research has shown that some teachers will be stationary for many years, perhaps for their whole career, in one of the five stages. This can be true for the novice stage; some teachers will be expected to engage in rule-governed performance of context-based teaching for the remainder of their careers. This is their belief about the essence of their performance.

Initial issues of concern by teachers

For sixty experienced teachers attending an introductory workshop on Context-Based Learning for Senior Science, issues of concern that were expressed in response to the question “What are your expectations for this workshop” are as follows:

<table>
<thead>
<tr>
<th>Teachers’ ‘self’</th>
<th>Justification for the vision of the new syllabus</th>
<th>Understanding the vision for the new Syllabus</th>
<th>Support for trial syllabus process</th>
<th>Nexus between schools and universities</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Personal Inspiration for senior science teachers</td>
<td>• Justification for the change</td>
<td>• Clarity of vision for Context-based design</td>
<td>• Support for the Trial Syllabus process</td>
<td>• The universities’ prerequisites be reinstated to favour chemistry and physics</td>
</tr>
<tr>
<td>• Cure for personal scepticism</td>
<td>• Showing what is wrong with the present, and why we must change</td>
<td>• Understanding teachers as authentic facilitators of student learning</td>
<td>• Help with implementing the syllabus in the classroom</td>
<td>• The universities adapt to the new student characteristics that this syllabus will produce</td>
</tr>
<tr>
<td>• Stimulation and energy for the trial teachers</td>
<td>• Gaining of confidence that students will benefit from the change</td>
<td>• Principles of the new pedagogy required by this syllabus</td>
<td>• Time to change and learn how to teach the new syllabus</td>
<td>• This syllabus might require universities to drop their standards</td>
</tr>
</tbody>
</table>

Table 1. Teacher Expectations of Professional Development Workshops

- Personal Inspiration for senior science teachers
- Cure for personal scepticism
- Stimulation and energy for the trial teachers
- Justification for the change
- Showing what is wrong with the present, and why we must change
- Gaining of confidence that students will benefit from the change
- Understanding that the students have the social and cognitive maturity to cope with the new learning tasks
- Understanding how context-based study helps students to retain their knowledge
- Confirmation that this change is state wide and supported
- Clarity of vision for Context-based design
- Understanding teachers as authentic facilitators of student learning
- Principles of the new pedagogy required by this syllabus
- Push chemistry and physics back into the school curriculum limelight
- Clarity about how to handle diverse student projects, and outcomes in the classroom
- How to cope with the removal of so many concepts from the syllabus
- Reduction in concern that the new syllabus has an assessment bias towards girls
- Learning if contexts increase or decrease the amount of English and maths teaching occurring in the physics lessons
- Understand how this syllabus is continuous with the new syllabus in 8-9-10
- Support for the Trial Syllabus process
- Help with implementing the syllabus in the classroom
- Time to change and learn how to teach the new syllabus
- Series of interesting and relevant and viable contexts
- Solid support base for teachers in this change
- The universities’ prerequisites be reinstated to favour chemistry and physics
- The universities adapt to the new student characteristics that this syllabus will produce
- This syllabus might require universities to drop their standards
- There be more university-school contact
The first four categories of teacher expectations displayed in Table 1 have a ready explanation if they are approached from the adult learning literature. Knowles (1987) has shown that when adults are asked to change and learn new behaviours and skills then they exhibit the following characteristics (in italics). The categorisations of teacher expectations adopted for this paper are compared to the Knowles positions.

- **Adults have a need to know why they should learn something** (Justification and Understanding for the vision of the new syllabus)
- **Adults have a deep need to be self-directing**. (Teachers’ ‘self’, Support for Trial Syllabus Process)
- **Adults become ready to learn when they experience in their life situation a need to know or be able to do in order to perform more effectively and satisfyingly**. (Teachers’ ‘self’, Justification for the vision of the new syllabus)
- **Adults enter into a learning experience with a task-centred or problem-centred or life-centred orientation to learning**. (Understanding the vision for the new syllabus)
- **Adults are motivated to learn by both extrinsic and intrinsic motivators** (Justification for the vision of the new syllabus); (Support for trial syllabus process; Teachers’ self)

The fifth category of teacher concerns - “Nexus between schools and universities” - is revealing because it shows that the senior science teachers at the workshop still have the vision that they are preparing students for university science. This common teacher belief will become very important in the implementation of the Trial 2001 syllabuses because ‘science for all’ is the vision promoted by these documents. This belief, if unchanged, will undermine the enactment of the new vision.

This concern reflects a bygone era when universities controlled tertiary entrance in terms of content and assessment of senior certificate courses. School-based assessment and curriculum development has been a distinct feature of high school education in Queensland since 1986. Since then the universities have accepted this process and consequently admit students on the basis of moderated syllabus requirements. These data show that the teachers are at the novice stage of skill development. Their primary need is for practical documents that give them ‘rule-governed’ behaviour that will start the process of their development. Secondly, they wish to engage in social-constructivist learning (Vygotsky, 1978) with others with relevant knowledge: trial teachers, academics and other teachers. Thirdly, they foresee that this context-based syllabus is going to need a lot of personal and professional development and that their schools need to be alerted to this. And their schools need to plan for the change in teachers and students, and to allocate the resources, and be prepared for the difficulties and struggles that will be part of the process for both the teachers and the students. Finally, the teachers see that they will need the authorities, the QSA who propose and manage the syllabus, to be available to clarify the issues that will inevitably arise as the syllabus vision is worked through into classroom learning.

### Teacher professional development needs
Planning for the future professional development needs of these teachers needs to ensure that the experience of workshop participation is given a chance to be translated and tested in the classroom. Action learning strategies provide powerful mechanisms for this process to proceed (Weinstein, K., 1998; McGill, I. & Beaty, L., 1993; Kemmis, S. & McTaggart, R., 1988).

In designing professional development activities a commitment to social constructivist principles are appropriate. These designs emphasise the rich and
complex learning that adults can achieve by reflecting together on personal experiences in a shared project. These opportunities will allow the participants to reflect in community on their rich experiences and thus derive the deepest and most indigenous learning possible.

Developing a sense of community among senior science teachers throughout the State will help overcome the limitations and frustrations of walking alone on such a radical pedagogical pathway. Programs of professional development that acknowledge a Zone of Proximal Development (ZPD) (Renshaw et al, 1997) can be created by learning designers so that assistance is provided by presenters, experts and peers. Learning within the ZPD can be divided into two stages:

Stage 1: The assistance to performance is designed by more capable others. The learner is assumed to have limited understanding. The expert takes the responsibility to offer structures, directions, graded activities, modelling, scaffolding and feedback.

Stage 2: Handover Stage. During this stage there is a steady decline of the expert responsibility for task performance and a reciprocal increase in the teacher as learner responsibility. The transition is made from other-regulation to self-regulation. The assistance offered by the experts is to accurately tailor assistance to the teachers by being responsive to the teacher’s efforts and understanding of the task goals. This stage is complete when the responsibility for tailoring assistance, tailoring the transfer and performing the task itself has been effectively handed over to the teachers.

In Conclusion

The 2001 trial syllabus has the potential to improve and expand the learning attained and retained by the students of Chemistry in Queensland schools. The vision of the new syllabuses is focused on ‘science for all’ and ‘learning in contexts’. In this paper, data have been presented from teachers in the very early stages of the implementation of these radical syllabuses. The data show little that is surprising but plenty that will need to be addressed if the implementation is to be successful. The conclusions from the analysis are follows:

- Teachers are showing predicted responses to change: they want to know why they should change, they want to understand the change and they want the required assistance to change. Importantly, they are also looking for a chance for personal renewal in implementing this change.
- Teachers are novices in the pedagogy of the new syllabus and they are looking for procedural knowledge to get them started
- The compulsory professional development offered by the syllabus authority (QSA) is only focused on accreditation and certification. This focus is insufficient if the teachers are to learn the new classroom pedagogy.
- Teachers need professional development activities that focus on their beliefs, on their values and on their assumptions about the vision for the senior subjects. If the culture of the senior science subjects does not radically change, this new syllabus is doomed.
- As expected with the freedom offered to Queensland teachers they are proliferating science contexts for their students. This will have ramifications for any future textbooks and other resource developments

References


The development and use of a pedagogical history for a key chemical idea: The case of ions in solution

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Abstract

A pedagogical history for a chemical idea combines a knowledge of the historical and philosophical background of that idea with what is known about the teaching and learning of that idea and is presented in a format and language that should make sense to a student. The development and use of such a pedagogical history for ions in solution is discussed in this paper. The emphasis is at the upper secondary or lower tertiary level and attempts to illustrate how chemical knowledge is constructed. An understanding of the nature of chemistry is a planned outcome of the exercise.

Introduction

Much has been written about the historical approach to the teaching and learning of chemistry. Schwartz (1977) suggests at least eight important outcomes of an historical emphasis in chemical education: chemistry is not a monolith rising toward omniscience but a subject often full of ambiguity; validation of ideas occurs through experiment, logic, mathematics, and even aesthetics; history dispels the notion of a single universal scientific method but reveals a wide variety of often intensely personal approaches; human diversity of scientists; the role of the imagination in the practice of science; value-laden choices made by practising chemists; social consequences of chemistry; and a revelation of the nature of truth albeit small-t truth. These eight outcomes are components of what Leopold Klopfer (1969) previously called scientific literacy. While the goals of scientific literacy are admirable Stephen Brush (1974) cautions us with respect to some of the possible outcomes. For example, young students might find the ambiguity and complexity of the origin of chemical ideas rather daunting and thus the historical approach could in fact rebound on us. However, Brush concludes that if the chemical ideas are introduced sensitively the historical approach could have “a redeeming social significance”. That is, a more realistic picture of science demonstrated through its history may reduce the hostility to science bred through an image of the robot-like scientist lacking emotions and moral values. Henry Bent (1977) also speaks about the difficult but desirable features of the historical approach to the teaching of chemistry. He compares the historical approach to the textbook approach and views chemistry in history as “risky, insecure, inductive reasoning, from properties to principles. It uses facts aggressively to capture concepts”. On the other hand, chemistry in textbooks is “safe, dependable, deductive reasoning, from principles to properties. It uses facts passively to illustrate ideas”.

Chemistry curricula as revealed in textbooks have been criticised for their emphasis on algorithmic problem solving rather than conceptual problem solving (Nakhleh 1993) and Lin (1998) has demonstrated that exposure to history of science cases in chemistry can enhance conceptual problem solving ability. Klopfer (1963) demonstrated that gains in the understanding of science and its processes followed a study of history of science cases by students in US high schools. In spite of these positive research results the use of history in the teaching of science and chemistry in particular has received only limited support. In 1989 the International History and Philosophy of Science and Science Teaching Group (IHPSST) was formed with only limited representation from chemists. In fact, the role of history and philosophy of science in the discipline of physics has received more attention than has its role in the discipline of chemistry. Bent (1977) argues that from a history of science point of view “chemistry is more complicated than physics. A match dropped is physics. A match struck is chemistry. Free fall is easier to describe mathematically than combustion”. The importance of showing our students how chemical ideas developed in modern society has, nonetheless, been highlighted on the international stage through such bodies as the IHPSST group and has now been incorporated as a requirement in the NSW Board of Studies chemistry syllabus. One of the reasons for the lack of application of history in chemistry teaching apart from those already mentioned has been the lack of supporting materials for teachers. This paper on a pedagogical history of Ions in Solution is illustrative of an attempt to provide such materials for chemical educators at the upper secondary and tertiary level.

What is a pedagogical history?

A pedagogical history differs from the history of science (HOS) cases published by Klopfer (1964) for secondary schools and the Harvard Case histories in experimental science for college and university students (Conant, 1948) in that it includes information relating to the teaching and learning of the particular concept from the research literature. The purpose of developing a pedagogical history for a chemical concept is to show students how a chemical idea was developed from rudimentary information into a substantive concept using important information about alternative conceptions that students have been shown to possess and combining this with important historical and philosophical considerations gleaned from the literature. The history and philosophy is designed to breathe life into what Norman Robert Campbell (1953) called “the dry bones of knowledge from which the breath has departed”. The knowledge of alternative conceptions is designed to

1 Presented at the Royal Australian Chemical Institute Chemical Education Conference in Hobart, Australia, February 2004.
assist students in making a transition from what is often common sense knowledge to scientific knowledge. I would now like to illustrate how a pedagogical history for the topic, Ions in Solution, was developed. The first stage was a historical and philosophical study of the topic.

**Ions in Solution-historical and philosophical considerations**

A historical and philosophical study of this topic in the context of the teaching and learning of chemistry was published recently (de Berg 2003). The major features of this study which are pertinent to the development of a pedagogical history are:

1. **The study used primary and secondary sources for relevant information.** These sources which date back to the late nineteenth century are invariably written in a style most unsuitable for student use. The techniques used and the experimental data obtained however are important insofar as they are related to concept development. I decided for the purpose of writing a pedagogical history to include only the techniques and data related to conductivity and freezing point depression. There were at least six other techniques I could have used but one has to be careful of information overload in a pedagogical history and I tried to pick properties which I could develop into a storyline that would make sense to students. For example, the property of freezing point depression enables me to talk about relaxing salt baths after a vigorous game of basketball or rugby, the spreading of salt on icy roads in cold climates, and the use of antifreeze for radiators. I selected more than one technique because of the suggested importance of experiment in deciding between competing theories. It is not intended that a pedagogical history be a faithful historical record of all relevant features related to the development of a chemical concept. A pedagogical history has its focus on student learning rather than history of science but selectively uses data from the history of science and pedagogical studies to faithfully represent how a chemical idea was developed. While a pedagogical history will not be comprehensive in its treatment of history it should reflect and respond to the best scholarship in the field in its selectivity.

2. **The topic is a good one for illustrating controversy in chemistry.** The electrolytic dissociation theory for salts in aqueous solution is arguably one of the most controversial in the history of chemistry. Arrhenius, van’t Hoff, and Ostwald favoured the “spontaneous dissociation in water” theory while Armstrong, Fitzgerald, and Pickering favoured the “spontaneous association with water” theory. This is an ideal situation for a pedagogical history because it shows how competing theories are treated in the development of chemical ideas. It illustrates how experiment cannot always decide between competing theories and also shows how anomalous data is treated in theory formation. The colourful language used particularly by Henry Armstrong really highlights the controversy and shows how religious insights impacted on Armstrong’s attitudes. For example, in reacting to the Xray study of sodium chloride by Professor William Bragg, Armstrong (1927, p478) said, “(This) is repugnant to common sense, absurd to the nth degree, not chemical cricket. Chemistry is neither chess nor geometry whatever Xray physics may be. Such unjustified aspersions of the molecular character of our most necessary condition must not be allowed any longer to pass unchallenged. A little study of the Apostle Paul may be recommended to Professor Bragg as a necessary preliminary even to Xray work,—, that science is the pursuit of truth. It were time that chemists took charge of chemistry once more and protected neophytes against the worship of false gods: at least taught them to ask for something more than chessboard evidence”. It turns out that both theories made contributions to our modern understanding of the dissolution of salts in aqueous solution in spite of the ultimately favoured dissociation theory. The dissociation theory is a good example of a theory that has undergone refinements ‘at the edges’ over time while the ‘hard core’ propositions of the theory have remained in place. The colourfulness of this debate lends itself to a dramatic presentation by students or staff.

3. **The role of ‘idealisation’ and ‘mathematisation’ in the development of chemical concepts feature in the development of the notion of electrolytic dissociation.** Mathematics did not have an easy passage into chemistry as illustrated by this study. Pickering (1897, p223) reacted to the role of numerical relations in chemical theory by saying, “However convenient such theories (dissociation) may be as working hypotheses their advocates should not have forgotten that they depend solely on the numerical relations alluded to, and that something more than this is required before such hypotheses can be raised to the level of acceptable theories”. Armstrong (1928, p51) also questioned the role of numerical relations in chemistry and concluded that, “we have to recover this (chemical feeling) or chemistry will be imperilled”. In the pedagogical history a reasonable amount of space is given to helping students observe that freezing point depression is proportional to the number of moles of solute and inversely proportional to the mass of solvent by using close to ideal data. The real data from Raoult’s study is then presented to the students for their reaction. Reasons for departure from the ideal case are discussed in relation to anomalies in the data. Idealisation of course marks the difference between medieval or Aristotelian science and modern science and featured in Galileo’s mathematisation of falling bodies. It features again in the development of the concept of ideal solutions and is an important lever to the emergence of mathematics in chemistry just as it was in physics. A pedagogical history can demonstrate that mathematical equations in science can possess a life of their own despite their common use in algorithmic problem solving.
Ions in solution-teaching and learning considerations

The literature (Ebenzer & Gaskell 1995; Ebenzer & Erickson 1996) on children’s understanding of the solution process reveals that children use terms like melting, disintegrating, and dissociating to describe what happens when sugar or salt dissolves in water but nothing is considered different about the way sugar and salt dissolves. Some consider the sugar and salt particles to fit into the air spaces left in the water during dissolving. Research (Taber 2002, p101) has shown that some children think that the solute ‘disappears’ when dissolved in water and this has at least two interpretations. By ‘disappear’ some mean that it is actually not present any longer but others mean it is present but not visible. However, some students who believed that the solute was present but not visible thought that the weight of the solution was identical to what it was before the solute was added. They thought the weight increased while there was undissolved solid present but decreased back to the original weight when dissolved. These are important ideas to address when developing the pedagogical history.

Structure of the Pedagogical History Draft 1

The overall structure is that of a storyline with diagrams, data, and questions interspersed with the text. Space is allowed for students to write in their responses to questions. The first draft has been published for trial on the website controlled by Professor Liberato Cadellini: wwwcsci.unian.it/educa/main.html, and consists of ten segments as follows.

1. The pedagogical history begins with a preamble which tries to interface with well recognised events related to the dissolving of solutes in solvents such as salt baths and the salting of roads in cold climates. The dissolving process is modelled taking into account the understandings students reveal according to the research literature.

2. The next section focuses on the dissolving of sugars in water and carefully establishes that the freezing point depression is proportional to the number of moles of sugar dissolved in the water and inversely proportional to the mass of water. At this stage only data from Raoult’s original studies that approximates the ideal values are used so that students can be assisted in deducing the mathematical relationships by inspection. Real non-idealised data are introduced later in the pedagogical history. The difference between a molecular lowering factor and a gram lowering factor is introduced to help students see how moles of solute is important in the relationship. The whole idea in this section is to illustrate what is meant by a scientific approach to a problem in terms of isolating variables and controlling them.

3. Having established a relatively constant molecular lowering factor for different sugars the molecular lowering factor for 1:1 salts is introduced. Five 1:1 salts and their molecular lowering factors reported by Raoult are tabulated and the students are challenged to think of a possible explanation as to why the molecular lowering factors are different from the sugars. They are led to consider the magnitude of the numbers as a possible clue.

4. The Arrhenius dissociation model proposed in 1887 is introduced and the students are asked to record what possible objections could be raised against it. Students are also introduced to the objections made by Armstrong, Fitzgerald, and Pickering.

5. Students are introduced to conductivity studies of salt solutions and how the Arrhenius camp used these studies to verify the presence of ions in solution. The Armstrong camp indicated that the ions had been created by the external electricity source and not by the spontaneous dissociation of the salt. The students are asked to indicate whether the conductivity data categorically prove that salts spontaneously dissociate into ions in aqueous solution or whether the data simply supports the notion.

6. Armstrong’s ‘association with water’ hypothesis is introduced to explain the salt data. This hypothesis focuses on the effect of the salt on water whereas the Arrhenius hypothesis focuses on the effect of water on the salt. Armstrong considers that the freezing point depression depends on the number of free hydrone (H₂O) molecules present in the solution. In the case of 1:1 salts two hydrone molecules per every salt molecule are associated with the salt and are no longer free whereas in the case of sugar molecules only one hydrone molecule per sugar molecule is associated. This explained, according to Armstrong, why the molecular lowering factor for 1:1 salts was nearly double that for sugars.

7. Students are asked to consider Raoult’s freezing point depression results for calcium chloride and barium chloride and to write down how Arrhenius and Armstrong would have explained the results. They are also asked to indicate how Arrhenius and Armstrong would have explained the fact that a calcium chloride solution conducts electricity.

8. The role of critical experiments which can help one decide between two or more competing models is introduced here. The advent of Xray diffraction is discussed and its role in indicating that the sodium and chlorine species in the solid common salt lattice was Na⁺ and Cl⁻ and not the neutral atoms is highlighted. Armstrong’s colourful published reaction to this suggestion is presented to students for their reaction. Armstrong had strong opinions about what techniques were appropriate for chemists and which techniques were inappropriate. This incident highlights the fact that the presentation of counter evidence does not always lead to theory change.

9. In Raoult’s original freezing point depression data anomalous results are present and students are asked to identify and respond to these. Some reasons for departure from expected results are given and students asked to select which reasons may account for the anomalies.

10. In summary students are asked to respond to some
questions related to dealing with conflicting models in science, the role of a scientist’s personality in theory acceptance or rejection, and the role of evidence and belief in the construction of scientific models.

Student reactions to the first draft
Preliminary trials of the first draft have been completed with eight BSc students studying chemistry as a major, minor, or elective study. The students were asked to complete the pedagogical history in their own time. Some completed the task before formally studying colligative properties and others after having formally studied colligative properties of solutions. Without exception student overall impressions are favourable. One student said, “I never knew this was such a controversial idea. It is great to see how the idea of dissociation developed”.

Students found the section on the quantitative treatment of the freezing point depression data particularly helpful in terms of the nature of a scientific investigation. One student said, “This has really helped me to understand the role of definitions and mathematics in chemistry”. Some students found the question, “What would the molecular lowering factor have been if Raoult had used 500 grams of water instead of 100 grams?” puzzling while others suggested that the solution would be more dilute and therefore that the molecular lowering factor would drop to one-fifth its value for 100 grams. This suggests that I probably need to establish through some examples that the depression is inversely proportional to the mass of water rather than assume it. The second draft will establish this.

Some students mentioned that they were not able to answer some questions without reading further ahead in the document. For example, determining what can vary in a freezing point depression experiment was not obvious to all students and some indicated that they decided on an answer only after reading the next few paragraphs in the document. This situation is consistent with the research reviewed by Chinn and Brewer (1993,p20-21) which showed that children and adults are deficient in their understanding of such methodological matters as controlled experimentation and the interpretation of covariation information. Perhaps this is why the students found the section on controlled experimentation so helpful. Some students also found it difficult to suggest an objection to Arrhenius’ dissociation model without reading further in the pedagogical history. In fact, students have implicitly accepted the presence of separate positive and negative species in solution for so long in their chemical education that they do not think to question why oppositely charged species do not attract and come back together as a unit again. This was a major objection raised by the Armstrong camp. On reading of Armstrong’s objection the students always express surprise that they didn’t think of the objection themselves.

Students had no difficulty in interpreting the calcium and barium chloride results using both the Arrhenius and Armstrong models and most were able to locate anomalies in Raoult’s data and give an explanation for it. Some students were particularly articulate in the way they answered the last three questions regarding conflicting models, the role of a scientist’s personality, and the roles of evidence and belief in theory formation. In relation to the question about the role of evidence and beliefs in the construction of scientific knowledge a second year student said, “Beliefs are the views and opinions that scientists bring to their work, while evidence is results or data that support a particular belief. In this article there were two beliefs concerning the dissolving of salt and sugar in water…..Arrhenius’ view of dissociation into ions led him to conclude that the conduction of electricity in a salt solution was evidence for dissociation while for Armstrong this was not evidence and he came up with an alternative explanation. Even in the face of strong evidence provided by physics, Armstrong would not give up his belief. Beliefs strongly colour how evidence is interpreted”. Students found the pedagogical history easy to read and informative about the way chemical knowledge is developed. I do not think this exercise would have been so helpful to the students if the storyline didn’t have appropriate prompts which students could locate in the text. These prompts act as scaffolding (Taber 2002, p73) to support the learners’ progress in knowledge acquisition.

Draft 2 of the pedagogical history will contain the changes already suggested as well as other refinements such as in the X-ray section. It is important to note that powder X-ray diffraction techniques distinguish between K⁺ and K for example because it is the electron structure that is responsible for the diffraction and K⁺ and K have a different number of electrons. Draft 2 will also contain a development of the equation, ΔT_f = ik,m, and an enhanced discussion of idealisation and mathematisation in chemistry. This latter addition will suit the tertiary edition of the pedagogical history but not the secondary school edition.

Conclusion
Early indications are that this is a project worth pursuing into further drafts and trials. The use of a pedagogical history in the teaching of chemistry should lead to a situation where assessment items in examinations will require not only typical problem solving activities but a knowledge of how chemical ideas came to be established. The primary purpose of a pedagogical history is not the teaching of history but epistemology as Heilbron (2002) has so adequately described. A greater understanding of how chemistry fits into the great scheme of the history of ideas in our civilisation should result.

References

to continue on page 9
Introduction
There are two major traps that await the unwary historian. One is to view the past through eyes that have already taken in much that passed between then and now. The other is to get sucked into the idea that there were key turning points at which new concepts came, apparently, out of the blue. This is to ignore the gradual build-up of such ideas in an international community of scholars. These traps are especially likely to befall the discipline specialist who seeks to become a historian without going through the hard grind of an Arts degree and subsequent years in graduate school. Exploring examples of both kinds, however, can lead to a better understanding of what we do now, and why.

First, let me remind you that you have probably come across examples of the two traps in your own studies and perhaps in your teaching. In the first category we could put the phlogiston theory, which held that something was lost (that’s the phlogiston) when a metal was burned in air. The theory was nicely self-consistent and it was only the advent of the gravimetric balance that finally brought it undone. Mind you, it took a while for the phlogistonists to abandon such a beautiful theory and they flirted with negative mass before they did so.

An example from the second category would be the development of the periodic table of the elements. Following his announcement in the middle of the nineteenth century, we gave the credit to Dmitri Ivanovich Mendeleev and only gradually have we come to accept the significance of Dobereiner’s triads, dating from 1817, and organizational schemes proposed by other researchers such as John Newlands whose work was rejected by the journal Chemical News on the grounds that it was too speculative.

While these two examples have been explored in some depth by historians and are often found in modern textbooks, I want to speak today about two ways of thinking about chemical bonding which emerged at either end of the second half of the nineteenth century and will probably be unknown to you. Before turning to the ideas, however, I should like to introduce the players.

Josef Loschmidt
The first case is that of Josef Loschmidt (Fig. 1). He was born in 1821 near Karlsbad in Bohemia, now part of the Czech Republic but then part of the Hapsburg Empire which had twin capitals in Vienna and Budapest and a major administrative centre in Prague. Loschmidt studied at local schools, then at a grammar school in Prague where he received a sound classical education. At the University of Vienna he studied physics and chemistry, but could not afford to pursue a research career. He failed to gain a position as a teacher, and never made a success of several attempts to prosper in the chemical industry. Eventually he made it into the classroom, and spent several years as a grammar school teacher in Vienna, during which time he published two major works. Then, and probably because of this, he gained a junior appointment at the University in 1866, and this led to his appointment as Professor of Chemical Physics in 1871, a position he retained until 1891 when ill health forced his retirement, and he died four years later at age 74.

Figure 1. Josef Loschmidt
Loschmidt researched in a number of what we would now regard as separate fields of science. One of his two major works, submitted in 1865 and published the following year, concerned the size of air molecules. Assuming a spherical shape, he calculated the molecular diameter as 1 nanometre. While this is somewhat larger than we would accept for such a quantity today, it is significant because • it reveals that Loschmidt believed in molecules, when many people in the 1860s did not • secondly, it is based on a mean-free-path treatment of gaseous particles (recall that the kinetic theory of gases was developed in the period 1848 to 1895 with input from such luminaries as Joule, Clausius, Maxwell, Thomson and Boltzmann, and thirdly • it leads to a fairly accurate value for the number of molecules in a cubic centimetre of gas – the so-called
Loschmidt number — as $2.7 \times 10^{19}$ which equates to the number in a mole as $6.048 \times 10^{23}$. The modern value for Avogadro’s number should be ingrained on your psyche, but in case you are having a few days off, I remind you that it is $6.022 \times 10^{23}$, so you can see that Loschmidt’s result was excellent.

Although Loschmidt did not have much contact with scientists outside Vienna, he did meet Boltzmann, who completed his PhD there in 1866, and he was always up with the latest theories. For example, in his declining years, he invented an air-cleaning device to remove bacteria from his room, a clear indication that he had rejected the still-prevalent view that diseases were caused by bad air (so-called ‘miasma’) in favour of causation by particulate living organisms.

**William Sutherland**

My second case draws of the work of Australian theoretical physicist and physical chemist, William Sutherland. He was born in Glasgow in 1859 and came to Australia in 1864 with his family, who settled first in Sydney and then permanently from 1870 in Melbourne. He studied at Wesley College and then at the University of Melbourne, taking his BA with first class honours in natural science in 1879. Awarded a scholarship for study overseas, Sutherland went to University College, London where he completed a BSc in 1881 with first class honours in experimental physics. Good Melbourne boy that he was, he did not enjoy this northern hemisphere experience, but he did have a job to return to. Nonetheless, he returned to Melbourne and embarked on a life of reading and research, supported by private coaching, university examining, frequent writing for newspapers, and occasional stints as a replacement for staff absent from the Department of Physics at the University of Melbourne. His applications for chairs at Sydney, Adelaide and Melbourne were rejected, but he published extensively in leading physics journals, and far eclipsed the output of appointees who had been favoured over him.

Sutherland’s work on the temperature dependence of the viscosity of gases led him to conjecture that the intermolecular $1/r^2$ force was merely the first of a power series, and that including the next term ($1/r^4$ – nowadays we would ascribe a higher power to it) gave a better fit between theory and experiment. He regarded this new force as due to the existence in all molecules of ‘polarized electric doublets’ (to quote his biographer). We shall see how this idea was transposed into the liquid domain and applied to the super-molecular structure of water.

Sutherland died in 1911 of heart failure, at the early age of 52. His brothers Alexander (a journalist and schoolmaster) and George (an inventor and journalist) died at similar ages of what was obviously a genetic defect. Their sister, Jane, was a talented painter who belonged to the Heidelberg group that included Roberts and McCubbin and she had her work hung in leading Australian galleries. Free of the curse on the male line, she died in 1928 at the comparatively ripe old age of 74.

Loschmidt’s chemical formulae

In 1861 Loschmidt published his Chemisches Studien in which he revealed a new symbolism for atoms and for inter-atomic bonding. Importantly, his formulae included a cyclic structure for benzene, some four years before the famous hexagon structure of Kekulé. At that time the standard depiction of structure was the ‘type formula’ exemplified here by Williamson’s (you might recall the Williamson ether synthesis, but this is not it) reaction scheme for the preparation of diethyl ether from ethanol and sulfuric acid, via ethyl hydrogen sulfate (Fig. 2).

![Figure 2. The standard depiction of structure exemplified here by the reaction scheme for the preparation of diethyl ether from ethanol and sulfuric acid.](image)

Loschmidt’s formulae were much more explicit, as you can see from those in Figure 3 for acetic acid and glycolic aldehyde. The large circle represents a carbon, the smaller ones hydrogen, and their bonding relationships are shown by touching circles. The oxygen circle is doubly inscribed, and – this is an important point – its presence in a carbonyl group, with a carbon-oxygen double bond, is emphasised by two interconnection lines. Similarly, nitrogen is represented by a triply inscribed circle and a triple bond by three lines (Fig. 4). The formulae shown here are for succinamide and succinonitrile. Figure 5 shows the famous benzene structure and the way it appeared in such molecules as phenol and anisole.

![Figure 3. Loschmidt’s representation of acetic acid and glycolic aldehyde.](image)

![Figure 4. Loschmidt’s representation of succinamide and succinonitrile.](image)
When I first came across Loschmidt’s structural formulae I was struck by their similarity to the symbolic logic of John Venn, which dates from 1880. Figure 6 shows the familiar example of the black cats. In fact, this symbolic logic goes back a hundred years before Venn, to the famous mathematician Leonhard Euler, who published it in 1768 in his delightfully titled ‘Letters to a German Princess’. Symbolic logic has been adopted by chemists and physicists in other contexts, too, because we can find it being used by G.N. Lewis in 1923 and by Coulson in his well-known book Valency (Fig. 7). Older members of the audience would no doubt have been raised on this text and so the interactions of 1s orbitals will be familiar to them.

Loschmidt’s formulations were never taken up, and within a few a few years a new regime had taken over and we find a very modern look about the formulae being drawn by chemists in 1878 (Fig. 8).

Sutherland’s theory of covalent bonding

The involvement of electrons in covalent bonding is firmly associated with the name of Gilbert N. Lewis, whose 1916 paper on electron-pair bonding is one of the landmarks of chemical theory. Like other ‘landmarks’, it had been preceded by some tracks in the sand, because chemists had long suspected that electrons were involved in some way. In a Faraday lecture in 1881, von Helmholtz had drawn on Faraday’s work on gram atomic weights and proposed that both positive and negative electrons were involved, and he soon received support from Walther Nernst for this idea. Indeed, it was such a good idea that it survived the discovery of the electron, by J.J. Thomson in 1897, as the unit of negative charge. The real positron was not to arrive until much later, of course, and then not in the realms of chemistry.

In the 1890s Sutherland turned from gases to liquids, his interest piqued by the properties of liquid water and the experiments by W.C. Röntgen – yes, he of the X-rays – on the temperature dependence of the compressibility of this strange liquid. Raoult had already hypothesised in 1882 that, since freezing point depression data suggested a molecular weight of 57 for water, it actually existed as a trimer. The polymolecular nature of water was extensively discussed in the 1890s, as an adjunct to the developing theory of ions in solution, and there were a number of suggestions along these lines. Probably the last of these was that of Henry Edward Armstrong, who in 1906 made specific proposals that the monomer, which he termed hydron, existed only in steam, while liquid water contained a dimer (hydrol), a cyclic trimer and possibly longer chains, in all of which the oxygen atom had four bonding partners (Fig. 9).

Sutherland had entered the discussion with a paper in the Philosophical Magazine in November 1900, in which he proposed that monomeric water existed only in steam, while the liquid was a mixture of the dimer (dihydrol) and trimer (trihydrol) which were in dynamic equilibrium via...
the monomer. This, like most of Sutherland’s papers, was a theoretical contribution, but he drew on published experimental results for latent heats of fusion and evaporation, specific heat, viscosity and dielectric capacity. By analogy with others’ work on metal oxides, he drew structural diagrams showing apparent bonds between oxygen atoms. He went on to suggest that positive and negative electrons were involved, with the neutral water molecule having equal numbers of each, and the dimer resulting from electron exchanges that led one molecule to have two negative electrons and the other two positive electrons, so that electrostatics held the dimer together. This scheme could not readily be extended to the trimer, and I think Sutherland fudged it a bit by resorting to ‘equilibration’.

Figure 9. Armstrong’s depiction of ‘dihydrone’ and ‘hydronol’.

He followed this paper with another in February 1902 in which he used musical notation sharp (♯) and flat (♭) to denote the two kinds of electron (+ and -), and the musical neutral sign (♮) to denote a sharp-flat pair ‘in which the ♩ and ♪ are much closer together than in their initial position’ and ‘rush together to form a neutron’. Although Sutherland is talking about positively and negatively charged electron-like entities, it is easy – with the benefit of hindsight – to make the analogy with G.N. Lewis’ electrons that come in pairs that we would now describe as having opposite spins. Lewis published his octet theory in 1916 but it only became popular after it was taken up by Langmuir in 1919. The spin concept came later, in the 1920s, as a result of Pauli’s characterisation of energy states supported by spectroscopic experimental evidence that electrons show two kinds of behaviour in magnetic fields.

The Faraday Society held a general discussion on ‘The Constitution of Water’ in April 1910. Sutherland contributed a paper to it and this was published in the Proceedings, from which we can see (Fig. 10) that he had extended his scheme of positive and negative electrons so as to account for di-, tetra- and hexavalent oxygen, and also depicted sodium chloride as NaCt while the separated ions were Na# and Clt. Sutherland was not present at the meeting and that brought an end to the discussion. A fair account of it appeared in Nature a few weeks later, and an abbreviated account in the Chemical News. As a matter of interest, a paper was also submitted to the meeting by Walther Nernst, but his paper was circulated to participants and referred to during the discussion but his paper was not included.

Writing in 1959, Norman Feather said that Sutherland was the first to use the word ‘neutron’, as he developed his ideas about positive and negative electrons. Feather went on:

Regarded in retrospect these views of Sutherland appear little more than fantasy; though there is a certain vague intuition of later ideas, there is no empirical necessity about his fundamental concepts … But it was an age of bewilderment in physics … and his fanciful picture of molecules and atoms, of electrons and neutrons was wholly innocent, it would seem, of the thought that some day it must meet the challenge of direct quantitative test, or pass into limbo. … No one else followed him into the intricacies of this speculation, but during the first years of the century Sutherland was not a lone romantic among physicists: his malady was partly of the age in which he lived.

The music stopped with Sutherland’s death within a year of the Faraday Society meeting and that brought an end to his speculation. Nonetheless, the mystery of water goes on, and from time to time we read of new experimental results, and new theories of the structure and composition of liquid water.

Let’s leave the last word to the poet D. H. Lawrence:

Water is H₂O, hydrogen two parts, oxygen one, but there is also a third thing, that makes it water and nobody knows what that is.

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Figure 10. The formula for trihydrol showing negative electrons (♦) and positive electrons (♣).
An IR investigation of the CO dipole direction and other properties: An APCELL experiment

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Introduction
Spectroscopy is a direct probe of molecular properties. The novelty of this experiment is the placement of a near-standard Fourier-transform infrared (FT-IR) spectroscopy in an applied context of relevance to physical chemistry, toxicology and organometallic chemistry.

For many years, there was disagreement about the direction of the carbon monoxide (CO) molecular dipole, which had major implications for how CO acts as a poisonous gas (in its binding to haemoglobin), or as a ligand in organometallic complexes.

Neither Lewis structure is very satisfactory. Structure I is a zwitterion, which obeys the “octet rule”, but places the negative charge on the more electropositive atom, and vice versa. Structure II minimises the formal charge, but does not obey the “octet rule”. Structures I and II predict opposite directions for molecular dipole.

Structures I and II also differ in their bond order. In this laboratory exercise, infrared (IR) spectroscopy is used to determine the bond order of CO, and hence infer the direction of the molecular dipole, as follows:

1. The vibrational transitions are used to estimate the harmonic frequency. The bond order can be determined from the frequency-bond-order relationship.
2. The vibrational transitions are used to determine the anharmonicity and harmonic frequency. The bond dissociation energy can be determined from the harmonic frequency and the anharmonicity. The bond order can be determined from the bond-length-bond-order relationship.
3. The rotational fine structure of the vibrational transitions is used to determine the rotational constant, \( B \), and hence the molecular bond length, \( r_e \). The bond order can be determined from the bond-length-bond-order relationship.

This laboratory exercise illustrates that spectroscopy is a direct probe of molecular properties, which have practical applications. (Spectroscopy is not just an academic exercise in quantum theory.) The observed gas-phase spectra provide direct evidence of quantisation and the bond order. This exercise is the only occasion when students make a measurement of any molecular bond length in the Deakin University undergraduate chemistry program. It is one of the few occasions where a bond binding energy (the “bond strength”) is determined. Furthermore, this laboratory exercise gives students the opportunity to gain “hands-on” experience with a Fourier-transform infrared (FT-IR) spectrometer, which is a common analytical technique in industrial and forensic laboratories.

Educational Template

Section 1 - Summary of the Experiment

1.1 Experiment Title
An IR investigation of the CO dipole direction and other properties.

1.2 Description of the Experiment
The infrared absorption spectra of gaseous carbon monoxide and atmospheric air (background containing carbon dioxide and water vapour) are recorded. The carbon monoxide spectrum is analysed in terms of molecular vibrations and rotations, various molecular properties and parameters, including the carbon-oxygen bond length, are determined from the spectrum.

The novel feature of this exercise is that the spectroscopic information are used to discuss the CO bond order, molecular dipole direction and other properties. An unusual feature is that the first overtone is measured (1,2), in addition to the fundamental vibrational transition.

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1.3 Course Context and Students’ Required Knowledge and Skills
This laboratory exercise is part of the Spectroscopy unit, which is a compulsory unit (subject) at the start of the third year. All students would have completed either a semester-long unit (subject) on spectroscopy, or a semester-long unit (subject) on analysis of biological molecules, in second year.

In addition, students who are majoring in chemistry would have completed a semester-long unit (subject) on “physical
chemistry⁴, including numerical analysis using Microsoft Excel, in second year. Explicit detailed knowledge of quantum mechanics is not required.

However, there is also a substantial number of non-chemistry-major students who have weaker numerical analysis skills than the chemistry-major students. Some of these students have difficulty with the language of physical chemistry, which is a mixture of scientific English and mathematics. This difficulty is reflected in the student feedback of Section 3 (Student Learning Experience), which shows that many students had difficulty with:

- comprehending that they had to fit an equation and
- fitting quadratic curves to experimental data.

1.4 Time Required to Complete
Prior to Lab 1.5 hours reading and pre-lab exercise
In Laboratory 2 hours laboratory and 2 hours computer laboratory for analysis of results
After Laboratory 2-3 hours report writing

1.5 Acknowledgments
Infrared rovibrational diatomic spectroscopy experiments are a standard part of the physical chemistry curriculum in many universities. There are several examples of HCl and CO spectroscopy experiments in textbooks and chemical education journals. For many years, Deakin University had an HCl infrared experiment, investigating the fundamental vibrational transition. The original source is unconfirmed, but is suspected to be a standard literature experiment (3).

The course of several years, the author modified the experiment by monitoring student learning and feedback from students and technical staff (4,5):

- introducing the pre-lab simulation exercise using an Excel spreadsheet (6);
- changing from HCl to CO gas (technical staff were concerned that leakage of HCl — although unlikely — might damage the FTIR instrument);
- introducing the analysis of the first overtone (1,2);
- introducing the extension exercise on quantum calculations; and
- introducing the contextual background of the CO dipole and implications for ligand-metal binding.

When developing this exercise, the author was unaware of the paper by Mina-Camilde et al. (1), which describes an almost identical exercise, but without the contextual background of the CO dipole and implications for ligand-metal binding. Professor Mark Spackman (UNE, Armidale) has a computer laboratory exercise on quantum calculations on CO, which provided the idea of the extension exercise here. The author thanks Associate Professor Bryce Williamson (University of Canterbury, NZ) for discussions about his CO experiment, which has lead to the extension exercise in this laboratory exercise. The author thanks Ms Jeanne Lee (Loyola College, Watsonia) for encouraging and helpful discussions.

1.6 Other Comments
There are occupational health and safety issues associated with this exercise. Carbon monoxide is an odourless, colourless, flammable, toxic gas.

Suggestions of alternative (safe!) gases, which could be used for this exercise, would be extremely welcome!

The gas cell is the one piece of equipment that is most at risk of breakage. Commercial 10 cm gas cells cost in excess of AUD $600. Specifications and detailed designs for much cheaper “home-made” cells are given in the literature (7,8).

The assessment criteria for this laboratory exercise, have been published previously in the description of another exercise from Deakin University (9,10).

The teaching-and-learning assessment described in this paper has been approved (EC 29-2002) by the Deakin University Human Research Ethics Committee.

### Section 2 – Educational Analysis

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#### Theoretical and Conceptual Knowledge

Students should understand that each rovibrational spectrum in this exercise corresponds to a “single peak” in the more extended IR spectra, which are encountered in the typical synthetic laboratory. Students will measure and compare wide-range IR spectra (similar to those in a typical synthetic laboratory) with spectra focusing on a particular vibrational transition (similar to those in physical chemistry texts). Students will be able to communicate the understanding that a particular vibrational transition with rotational fine structure looks like a single vibrational “peak” when the scale of the spectrum is changed.
Students should appreciate that molecular energy levels are quantised.
These fundamental concepts underpin the entire exercise. Students will measure and compare IR spectra.
Students will be able to communicate the understanding that most of the spectrum has near-zero absorbance except where the photon energy matches quantised changes in molecular energy.

Students should understand that absorption of a photon results in a transition from a lower-energy level to a higher-energy level. The quantised changes in molecular energy result in spectral peaks. The increase in molecular energy corresponds to the absorbed photon’s energy.
Students will analyse spectra using relationships derived using the “selection rules”.
Reasonable results are obtained only when the assigned quantum numbers for the spectral transitions obey the “selection rules”.

Students should understand that symmetry constraints (“selection rules”) determine which energy gaps can correspond to an “allowed” transition.

Students must understand that solution of the Schrödinger Equation predicts formulas for the vibrational and rotational energies of simple molecules. Hence, these formulas, coupled with the selection rules, will predict the photon energies of the various allowed transitions.

Students should be able to relate spectroscopic information and concepts to bonding and reactivity concepts in other parts of the chemistry syllabus.
Students will use bond-order relationships to predict the bond order on CO and the direction of the molecular dipole. Students will be asked to apply this knowledge to bonding and reactivity concepts in other parts of the chemistry syllabus.
Students will be able to rationalise and predict metal-ligand binding in other parts of the chemistry syllabus using spectral information, and be able to communicate this understanding.

Students should be able to exercise judgement about what is (or is not) relevant in the context of the exercise, judgement about what is (or is not) significant in the context of the exercise, and judgement about what is (or is not) important in the context of the exercise.

There must be sufficient data, details and discussion in the main body of the report, so that a student (classmate) who has done everything as the student writer, except this exercise (or this unit), can understand the report.

Students must decide what to include or omit from a formal written report. They are given the demonstrator’s assessment and feedback pro forma. They are encouraged to seek help from the demonstrator.

Scientific and Practical Skills

Students should be able to operate a FTIR spectrometer.
Students prepare samples and use the spectrophotometer to make measurements.

Students will record spectra of the samples, which are consistent with literature spectra.

Students should be able to transfer gases from gas cylinders to sample cells.
Students will use a spreadsheet package to collate, display, and analyse observed data.

Students will obtain linear or quadratic plots, similar to those in textbooks and the scientific literature. The experimentally determined parameters will be in good agreement with literature values.

Students should be able to collate, display and analyse data using a spreadsheet.
Generic Skills

| Students should be able to work in teams, and to plan and manage their time effectively. | Students must divide tasks between themselves at different stages of the laboratory exercise. | Students will complete the allocated tasks with minimal conflict. |
|States must be able to use and interconvert units correctly. | Students should be aware of and convert between energy (units of kJ mol\(^{-1}\)), frequency (units of s\(^{-1}\)) and wavenumber (units of cm\(^{-1}\)) quantities. | The experimentally determined parameters will be in good agreement with literature values. |
| Students should (further) develop communication and generic skills \(11,12\), including the ability to use appropriate computer programs \(13\). \n\textit{Note: The semester-long spectroscopy laboratory program at Deakin University is one of a series of laboratory programs specifically intended to foster report-writing skills and use of computer packages (eg word processors and spreadsheets).} Students are given the opportunity to submit draft reports for comment. This aspect of the curriculum is not an integral component of the current exercise. | Students are given the opportunity to submit draft reports for comment. Students are encouraged to consult their demonstrator on the report writing style and use of appropriate computer programs. | Students will present a formal written report, which satisfies the criteria set out on an assessment and feedback \textit{pro forma}. |
| All of the above knowledge and skills. | By preparing a clear, well-structured formal report, students will organise their knowledge and understanding and to consolidate learning \(14\). | Students demonstrate that their knowledge, skills and understanding … satisfy the stated and implied criteria and they have met [or exceeded] all the other requirements … \n\textit{Note: This criterion is an extract from the Faculty guidelines on grading and assessment. It is clearly communicated to students during the semester and is the basis for assessment of all laboratory exercises and assignments.} |

Section 3 – Student Learning Experience

**Explanatory notes to Student Learning Experience**

In 2003, almost 30 students completed this laboratory exercise and provided feedback on the Student Learning Experience. Most negative feedback commented on the mathematical analyses (this laboratory exercise requires students to \textit{comprehend} that they had to fit equations to the data and then to perform the fits). The following are anonymous comments, reflecting the range of feedback.

3.1 \textbf{Did this experiment help you to understand the theory and concepts of the topic? If so, how, or if not, why not?}
\begin{itemize}
  \item S1: Yes it assisted in my knowledge of CO and the reasoning behind its ability to act as two diff. things.
  \item S2: Yes, relationships concerning bond order were understood.
  \item S3: Yes, much better understanding of equations and spectra detail.
  \item S4: Yes, because some research is need to understand the formulae.
  \item S5: Yes. The practical helped show how the calculations can be related to obtaining ‘real’ information about molecules
\end{itemize}

3.2 \textbf{How is this experiment relevant to you in terms of your interests and goals?}
\begin{itemize}
  \item S1: It wasn’t except for my goal of passing
  \item S2: CO; relevent in forensics due to its toxicity. Theory quite interesting
  \item S3: Very, want to do well in subject.
  \item S4: Helps me understand rotational and vibrational spectroscopy
  \item S5: This experiment helped clearify some calculations which are required in SBC313 spectroscopy
\end{itemize}
3.3 Did you find this experiment interesting? If so, what aspects of this experiment did you find of interest? If not, why not?
S1: I did find some of the information obtained from the spectra interesting
S2: Yes, CO has a triple bond
S3: Yes, like dealing with molecules that have a biological/biochemical effect
S4: Yes, how molecules move when light is absorbed
S5: Evaluation of data, i.e. calculations were 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 I think there is
S2: Yes and no; It is difficult without help and is very time consuming
S3: Yes, not really time during lab work, but enough time during spectra analysis
S4: Definitely not
S5: Sufficient time for experiment

3.5 Does this experiment require teamwork and if so, in what way? Was this aspect of the experiment beneficial?
S1: Yes it does particularly the research and understanding the equations
S2: It could
S3: Yes, in obtaining spectra
S4: Yes, to talk through concepts with others
S5: Teamwork is not essential, however very helpful to be able to correlate with team members and colleagues

3.6 Did you have the opportunity to take responsibility for your own learning, and to be active as learners?
S1: Yes I believe that helping each other also assists individual learning
S2: Yes but required additional help
S3: Yes
S4: Yes
S5: Yes, the calculations required further investigation for clarity and better understanding

3.7 Does this experiment provide for the possibility of a range of student abilities and interests? If so, how?
S1: I think some of the equations were quite difficult
S2: NO, can get very confusing more guidelines needed
S3: Yes, computer work, maths skills, etc
S4: Note sure
S5: Students’ use of computer software to aid in calculations is potentially improved

3.8 Did the laboratory notes, demonstrators’ guidance and any other resources help you in learning from this experiment? If so, how?
S1: The unit guide was helpful
S2: Yes & no. Yes cales were entered
S3: Yes, for literature values and use of eqns
S4: Yes, to understand it
S5: Demonstrators guidance was essential in this experiment as he helped out with some difficult calculations

3.9 Are there any other features of this experiment that made it a particularly good or bad learning experience for you?
S2: Bad → Why so many calculations. Did not know this was a maths subject
S3: Hard to know where to start in analysing spectra
S4: good – using excel for graphing etc. bad – time to understand and complete tasks
S5: Calculations helped develop problem-solving skills

3.10 What improvements could be made to this experiment?
S1: The explanation of the equations
S4: Try to make it less time consuming
S5: In addition to CO spectrum analysis, further analysis of a diatomic molecule with a single Lewis structure and a single bond could be made

3.11 Other Comments
S4: have a nice day! :)
S5: No

References
Chemical education: The element of change, a personal perspective

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Introduction
I have been teaching Chemistry at the tertiary level for nearly 35 years – more or less half this teaching experience has been in an Asian country, and the other half has been in the South Pacific. The main concern in Asian Universities and in the University of the South Pacific (USP), unlike that in most Australian Universities, is not about decreasing student numbers but about teaching Chemistry effectively to ever-increasing student numbers.

How are we coping with making Chemical education attractive and meaningful to larger numbers? Our students too sometimes distrust science and the problems perceived to have been caused by science. What are we doing to combat this? Our tactics and strategies may help Australian educators.

Exploiting the skills possessed by the students
Because of changes in the school curriculum and a different emphasis on what is important and what is not important in the school curriculum, the student of today who opts to do Chemistry in the University arrives with many skills that an undergraduate of 35 years ago did not have. At the same time, the student of today arrives minus some of the skills a student of the past clearly possessed. How have we old teachers adapted? We try to make the most of the skills already possessed by the students.

For example almost all our undergraduates of today are computer literate at a basic level. On the other hand, their skills in listening to a lecture and taking down notes at one and the same time are not very good. When taking down notes, many students tend to take down everything that is being said, and thus miss comprehending the lecture. They, for some reason, have not learnt to comprehend, quickly abstract the important points and put these down in the briefest form. Do we spend time at the university trying to teach students a skill that was valued in the old days? No, we exploit their new skills.

Students are asked not to take down all the notes but are encouraged to listen, comprehend and ask questions at the end of the lecture. Students are assured that the visual aids (projected by the overhead projector and displayed by Power Point) and the notes used by the lecturers will be made available electronically. In addition, some of our lecturers provide copies of the lectures in the library for overnight borrowing. Attempts are being made to request for class share allotments for some courses where lectures, tutorials, and other course materials could be posted on the internet to give ready access of these materials to the students.

Accessing material electronically does not make the art of note-taking dispensable. Students still have to go over the material, understand it and extract important data. Neither does accessing material electronically make listening and comprehending dispensable. At the lecture, the lecturer explains a great deal and students learn by asking for clarification. It is just that students are freer to listen and understand when they are not under the pressure of simultaneously writing rapidly.

Are we coddling and spoon feeding the students? No, I don’t think so. Old ways must give way to the new. The test question is: Is the new way effective? I assure you it is. The students appreciate it and benefit by it. And word gets around that the Chemistry Department is vigorously adopting new ways to combat problems. At the end of every course students are given a Course Evaluation Form and asked for their comments. The feed backs we get regarding the strategies we have adopted are encouraging.

Our graduate students do not need to do an arduous search of the literature for work that has already been done in certain areas of investigation. For instance those working in the area of Natural Products Chemistry access the excellent NAPRALERT database maintained at the University of Chicago, Illinois. All the required information arrives within a couple of hours of a request having been made. Information Technology (IT) has taken the drudgery out of literature search, which is an essential and vital part of research work but is time consuming and dull if done in the old way.

Students are helped by qualified staff to access databases. Rapid access to databases saves time and allows the student to devote more time to reading and doing assignments and planning and carrying out research projects.

Similarly, our graduate students who work in the area of Marine Chemistry can access the Marine Lit database produced by researchers at Canterbury University in New Zealand. All the required published information is available on a CD-ROM disc which can be readily installed in a couple of computers and the students are taught how to access the data. The Canterbury University researchers also supply updates.

Teaching the ability to search non-electronic literature has not been neglected. In many research areas, students still have to rely on non-electronic literature.

Information technology aided instruction at USP
The University of the South Pacific (USP) is a dual-mode teaching institution – instruction is available both face to face (On Campus) and through Distance Education (also called Extension Studies). In the South Pacific, the homes of Extension Students are spread over 33 million square

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1 Presented at the Royal Australian Chemical Institute Chemical Education Conference in Hobart, Australia, February 2004.
kilometers in the Pacific Ocean. Their homes are located in 12 widely separated Pacific Island nations. Information Technology has provided the means for bridging these gaps.

The Extension Centres in the member countries provide support services for the students. A satellite link (USPNET) provides the opportunity for satellite lectures and tutorials and video and audio conferencing. These are conducted by staff at the main campus in Fiji. Assignments are sent, marked and returned by e-mail.

Extension students are provided with specially prepared course materials in Chemistry. Care is taken not to sacrifice clarity for the sake of brevity. At the end of a topic there are tasks and questions. These are designed to make the student pause, and think about, review, make notes on and reinforce what has been read. Answers are provided so that students can assess their own performance. Any problem can be discussed during tutorials. Students sit for topic tests at the various centres so that they and their teachers can keep track of their progress. Unfortunately, no study has been done to compare student performance in the two modes.

The extension chemistry courses are confined to the First Year and Pre-degree (Foundation) levels. Students who succeed in completing these courses can opt to enroll in on campus courses at higher levels. Teaching extension courses at higher levels will have to wait until adequate support facilities are made available.

Course content in chemistry
When I first started teaching (now that was about 35 years ago), advanced theoretical chemistry formed a prominent part of the undergraduate course.

We at USP have reduced the theoretical content of many chemistry courses and have added new courses to emphasize the applications of chemistry. For example instrumental organic analysis is an important area of study for chemistry students. It enables a student to elucidate the structure of an unknown organic compound and confirm the structure of a known compound. It is important for the student to be able to interpret the spectral data provided by the analytical instruments. If technical help is not available he/she will also have to learn to use a sample of an organic compound, operate the instrument and obtain the spectral data. It is not necessary for the student to know exactly how the instrument was built or every minute detail about what chemical and physical theory its workings are based on.

Now theories are very important. They show us the forces that lie behind so much of what we see in the laboratory. We have not abandoned the teaching of theories altogether. For example structure reactivity correlations in the area of physical organic chemistry are taught to postgraduate students doing research in a relevant field. However, the majority of students in a large class find too great an emphasis on the study of theories – well too theoretical and irrelevant to their needs. It should be pointed out that the degree course at U.S.P. is a general degree course and an honours degree in chemistry is not offered. Both a general degree course and an honours degree in chemistry were and are offered in the university in Sri Lanka where I taught.

The explosion of knowledge in Chemistry has given us a vast field from which to select material and to design our courses. There are many exciting, interesting subjects in Chemistry that bear a direct and obvious relationship to everyday life. These engage the minds of almost all students.

At USP we have revamped some of our courses to suit the needs and interests of the students. Popular topics include Marine Chemistry, Environmental Chemistry\(^2\), Natural Products Chemistry and Medicinal Chemistry.

The Department of Chemistry has established a Chemistry Advisory Group and representatives from the Stakeholders (for example The Fiji Sugar Corporation and Douglas Pharmaceuticals) are members of this group. Industries provide materials for research and research projects suggested by Industries are undertaken by some postgraduate students.

Meaningful/relevant laboratory work
Many chemistry students find laboratory work dull and uninspiring unless the experiment is related to everyday life. Otherwise Chemistry becomes an abstraction.

From past experience I have found that experiments such as extracting and identifying caffeine from tea leaves\(^1\), nicotine from tobacco, glutamic acid from human hair\(^4\), anthocyanins and flavonoids from flowers, amino acids from potatoes, kavalactones from kava\(^5\), peanut oil from local peanuts, estimating the alcohol content of local (that is Fiji) beer\(^6\) and evaluating the vitamin C and limonene content\(^7\) of citrus fruits and peel respectively were stimulating.

One experiment that caused amusement as well as interest was the following: Students were asked to drink commercially sold fruit juice which contained the preservative sodium benzoate. They then, after a short interval, collected their urine and isolated hippuric acid. Hippuric acid is derived in the liver from a reaction involving the biochemical glycine, which is present in the liver, and sodium benzoate. The students were interested to learn that the body does not assimilate the chemical additive in preserved fruit juice and that the liver helps to eliminate it from the body.

In the case of most of these experiments, a lead was given and it was the 300 level students themselves who tracked down the necessary information and theory and designed the experiments.

Postgraduate students who undertake research projects relish work that is related to their environment and is relevant to their country.

Students’ perception of science
In the early 20\(^{th}\) Century, there was a widespread belief that science could solve all human problems and bring eternal health, wealth and happiness to one and all. Today, many people are disenchanted with science and blame
science for the vast majority of modern problems. This is unfair. Science is no more (or less) than an effort to understand our universe and everything in it. The practical applications of scientific knowledge have brought comfort and prosperity to many. However, the overuse, misuse and abuse of scientific knowledge have created many problems. Jettisoning scientific knowledge in order to get rid of some of its ill effects, foreseen and unforeseen ill effects, is like throwing the baby out with the bath water. Chemists, chemistry and chemicals have had some bad publicity in the recent past.

Agrochemicals, it has been pointed out, have polluted the air, earth and waterways and poisoned plant and animal life. But let us not forget that agrochemicals have eliminated great evils – hunger, starvation, famine and death. These evils were enormous compared to the problems that have been created by agrochemicals.

And there is a cure for the problems caused by agrochemicals. Sometimes the problems are due to the fact that the chemical itself is harmful. Then it should be tested and banned. Often, the harm is caused by overuse. Then educating farmers through an awareness campaign is the answer. Only science and the will to use science for good can solve the problems created by science.

Right now, the Chemistry Department at USP has a postgraduate research project in which we are trying to isolate biodegradable (natural) agrochemicals (nematocides to be exact) from marine sponges.

What is true about agrochemicals is true about medicines. Decades of research by chemists have produced well stocked pharmacies and the treatment for many diseases. But the woes brought on by the unrestricted popping of painkillers, tranquilizers and sleeping tablets, not to mention vitamins which are freely available over-the-counter has caused harmful side-effects. The cure is regulation in the use of medicines, regulation in the use of alternative medications and diet supplements and a creation of public awareness regarding the dangers of misusing a good thing.

The Chemistry Department at USP has isolated a natural pesticide from the body walls of South Pacific sea cucumbers. The pesticide is effective against the molluscs, which are hosts to the parasite, which causes schistosomiasis, a tropical disease that affects thousands of Africans.

What has been said about agrochemicals and medicines can also be said about cleaning agents, plastics, chemicals used in refrigeration systems, chemicals used in vehicles, chemicals used in the cosmetics industry and many more.

We, teachers at the University of the South Pacific, are doing all we can to create interest among students in Science in general and in chemistry in particular. We hope mistrust in Chemistry will turn to trust.

The Chemical Society of the South Pacific and the Chemistry Department at USP have been popularizing Chemistry through the Chemistry Outreach program in Secondary Schools and through various activities on the annually held USP “Open Day”.

Literature Cited
3. CH 100 Laboratory Manual, (2003), The University of the South Pacific, Suva, Fiji.
Imagine a world where only rich people could afford soap, clothes were available only in drab colours and there were no refrigerators, air conditioning units or nylon fabrics. In this very interesting book, Sharon Bertsch McGrayne describes the personalities behind important discoveries, showing the human face behind the work in the laboratory. She presents a balanced account, highlighting both the positive and negative aspects of the manufacture of nine major chemicals or chemical processes. Readers are able to form a mental picture of the person who carried out the work as well as the social and political context in which the developments took place. This is welcome, since most introductory chemistry textbooks present only the process; the context is seldom mentioned.

The first chapter focuses on Nicolas Leblanc’s invention of a process for making washing soda for the industrial manufacture of cheap soap, textiles, glass and paper. It might come as a surprise to readers that soap was not widely available to the general population until the 1850’s. Leblanc’s process ushered in the first of the large-scale processes for manufacturing chemicals. Before washing soda was available on a large scale, soap was manufactured by small family-run concerns and was sold as a luxury item to the rich. The German chemist, Justus von Liebig, declared in 1856: “the quantity of soap consumed by a nation is a measure of its civilization.”

The 1850’s also saw the introduction of the first synthetic dye. The schoolboy, William Perkin was trying to synthesise a substitute for quinine. Instead, he discovered a beautiful purple dye known as mAUve in the textile industry. UntiI Perkin’s synthetic dye became available, coloured garments were available only to those who could afford the cloth made with expensive dyes derived from natural sources. His discovery gave rise to the dye and pharmaceutical drug industries. In 1869, ten years after the synthetic mauve dye became commercially available, Perkin synthesized alizarin, an artificial red dye, which was sought after by the military. The large-scale production of alizarin red represented the first time that a product, formerly derived from natural sources, was manufactured by an industrial process.

I suspect that not many people have heard of Thomas Midgley, yet he made a vital contribution to the development of the motor industry. He majored in mechanical engineering at Cornell University and was a self-taught chemist. After a year with the National Cash Register Company, he went to work for Charles Kettering, the owner of the Dayton Engineering Laboratories where he carried out studies on anti-knocking agents. Using a version of the periodic table published in 1913, Midgley moved from a hit-or-miss approach to research to a project based on fundamental scientific principles. In 1921 the first sample of tetraethyl lead was synthesized in Midgley’s laboratory and leaded petrol went on sale to the public in 1923. In spite of concerns about exposure to lead, the public was enthusiastic about the product and enjoyed their enhanced mobility. By 1960, leaded petrol accounted for 90 percent of fuel sales for motors cars in the United States. Not only did Midgley’s work change the face of the motor industry, he was responsible for the development of non-toxic substances to be used as a gas for the refrigeration industry. In 1929 only about 15 percent of American families owned refrigerators although the principles behind refrigeration had been known for about 100 years. Early coolant gases included chemicals such as ammonia, methyl chloride and sulfur dioxide which were toxic. Frigidaire were interested in cooling large public spaces such as movie theatres and railway carriages and approached Midgley to carry out research into finding a suitable alternative to the gases available at the time. Within a short time, Midgley and his co-workers had identified a new class of compounds, the chlorofluorohydrocarbons based on knowledge of the periodic table as well as data on boiling points, volatility, stability and lack of toxicity. When Midgley unveiled dichlorodifluromethane at the annual meeting of the America Chemical Society in 1930, there was no notion that many years later, it would be found to be responsible for the depletion of the ozone layer. Refrigeration had an enormous impact on society and many lives were saved since vaccines and food could be preserved more easily. It changed shopping patterns as fresh food no longer had to be consumed shortly after it was produced.

Wallace Hume Carothers was the mastermind behind one of the great technological developments of the twentieth century, namely the conversion of simple molecules into polymers. He graduated from high school in 1914 and spent a decade struggling to qualify as a chemist. After working at Harvard University for a few years, Carothers accepted a position with Du Pont where he carried out the research that would transform the organic polymer industry. He synthesized the first polyeUsters showing that polymers were macromolecules consisting of long chains of monomers held together by covalent bonds. In 1930, Carothers and his team produced Neoprene and polyester and five years later the team synthesized nylon. The properties of the new synthetic fibre were superior to those of natural fibres such as silk in that nylon was stronger, more elastic and more resistant to rot, mildew and moths. Nylon, the first completely synthetic fibre, was marketed in 1940. While Midgley was outgoing and gregarious, Carothers suffered from various illnesses including bipolar disorder and committed suicide in 1937 a few days after his forty-first birthday.
The developers of several other chemicals are discussed in this book including Muller and DDT, Hackland and the purification of water, Haber and the production of ammonia and Patterson’s campaign to introduce lead-free petrol. McGrayne has concentrated on painting a picture of the personalities behind the discoveries rather than writing a conventional chemistry textbook. It is a pity that the one chemical structure included in the book, namely that of DDT, is incorrect in that the aromatic rings are drawn as if they were cyclohexane derivatives.

Chemists and teachers of chemistry at both secondary and tertiary level will find this book interesting as it provides much in the way of background material which could be used to foster an interest in chemistry. I persuaded my niece, a psychology and commerce undergraduate, to read a chapter from the book. She chose chapter 2, which describes the work of Perkin and the development of the dye industry. When questioned, she said that the book had been “quite informative and provided comprehensive historical background. It justified why the discovery was important and its impact on society.” Although she found that there were inconsistencies; the material varied from being technical to being suitable for a layperson, she nevertheless felt that it was an interesting read.

I would recommend this book to any chemist or chemistry teacher who is curious to learn about the man (the Prometheans are all men) behind the invention or discovery of some of the most important chemicals produced in the last 200 years. There is an extensive bibliography, 38 pages, for those who want to do further reading.

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The word on chemistry

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Who was it that said that one had to be mad to study chemistry? Such a broad and derogatory statement must surely have come from some nutty person who has neither shared in the subtleties of stoichiometry, been captivated by the charms of catalysis, nor experienced the ecstasies of electronegativity.

I had, at one point, decided (well, suspected) that stoichiometry was derived from the sense of having stoicism, that is, being a Stoic, as the idea of being unchangeable in appearance and outlook seemed to fit with that of the neat, unalterable, elemental relationships of chemical compounds and reactions. Here my logic and the actual facts of the matter diverged leaving me with the newly-won knowledge that Stoics were some hard-nosed philosophers following Zeno, a fellow who sat on a porch under a portico called a stoa at the Megali Stoa or Grand Lodge in Athens and told us with a straight face to accept whatever life dished out as being preordained and unavoidable.

Trying to separate the stoichiometry of elements from the elements of stoichiometry proved difficult. Being stoichiometric emerged as having the condition of being made up of elementary steps while a Latin elementum of unknown origin was equivalent to a Greek elementary step called a stoichon. Allowing myself great latitude, I conjectured that Zeno would be in his element having climbed steps to get to the porch, then I left the subject altogether.

Investigations into catalysis were somewhat more rewarding in that cata, a quite common prefix, came from a Greek kata, for down or wholly depending on the context, and gave direction to throwers, casters and sitting bishops in catapults, catastrophes and cathedrals. Coupled with lyein, to loosen or dissolve, katalyein eventually gave us catalysis which was originally to completely dissolve but which now describes a process influenced by an agent acting to alter the status quo but remaining unaffected by the reaction and fate of those involved (like a former associate of mine). This suffix also found its way to electrolysis and autolysis (also to paralysis for disabled at the side) and to lysis, lost and loose. I did conjecture that lye soap might connect by loosening dirt but this is said to come from lavare, to wash, my conjecture ending up in a lavatorium.

The negative bit of electronegativity comes straight from the Latin negare, to deny or say no, while the electro bit goes back over 3000 years to Greece. The Greek word for amber was (and is) electra, which was also the name of the daughter of Agamemnon and Chrysothemis. Like Oedipus, Electra, meaning brilliant, had a mother complex, only her’s was one of hatred as Mum and her boyfriend had bumped off Dad causing Electra to become electrified into a desire for revenge. I assume that Electra was attractive – so was electra, i.e. amber, due to its tendency to build up static charge, subsequently giving off brilliant sparks when discharging. Anyway, a bright spark called Lorentz theorised that zillions of tiny things caused this charge and in 1892 duly named them electrons which duly converted to and explained electricity once they got mobile. Whether amber or electra, it was valuable, as was electrum, an alloy of gold and silver and other precious metals.

On being nutty, I’m not sure how such a term achieved its current derogatory connotation (probably something to do with the head being called a nut) but it is certainly the condition of being a nut, earlier a nute or a note or a knut, all stemming from the Latin term for a nut or kernel which was nux or nucis. If a Roman spoke of a nut, then nucalis would have been uttered, whereas a little nut gave rise to a nucleus. One can have a nucleus in a cell and one can have a nucleus in an atom and one can have the nucleus of an idea – obviously something small but with great potential - and biologists speak of even smaller nuts called nucleoli. By the way, our atom is from atomos from a- and tomos for not cut, the cutting tomos bit ending up in microtomes and tomography but, unsurprisingly, not in hacking Algonquin tomahaks.

Nutty things can be useful, for example a concoction of pistachio and almonds nuts (noga) blended with sugar sweetened the palettes of the Provencal French as nogat and nogat while, if it was felt necessary, one could take a nut-derived emetic called Nux Vomica full of nasty alkaloids from the Strychnos nux vomica tree, hence one would administer strychnine to cure a severe case of poisoning.

Sneaking back to electra, I had a late thought that this might connect with elections. Investigations did yield an Electrix, the wife of the German Elector, but the whole thing went back to elegere for e- and ligere, fit for to choose. This looked a bit like ligare which was to bind, perhaps by means of ligatures, certainly by ligands, but I could not connect them together nor could I link lignum, or wood, engendering lignin. There was, however, a note suggesting a lexiconic leaning toward all of the terms possibly having the basic meaning of being bendable but I am unsure if our elected officials would appreciate being called bent, though they might prefer being described as both eligible and elegant!
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