# RACI

## Chemical Education Division
## 1998 National Conference

# Bridging the Gap

# Proceedings


Editors:
D.M. Druskovich
& G.T. Klease





...sland
...ITY
...he First.


Royal Australian
Chemical Institute

# Bridging the Gap

Proceedings of the 1998 RACI Chemical Education
Division Conference
held at Central Queensland University, Rockhampton,
Queensland.

2-6 July, 1998.

**Editors: D.M.Druskovich and G.T. Klease**

These *Proceedings* are a selection of papers presented at the Royal Australian Chemical Institute Chemical Education Division Conference held at Central Queensland in July, 1998.

All papers included in these *Proceedings* have been fully refereed before acceptance by the editors.

Referees:

Ms. Trish Andrews, Central Queensland University, Queensland
Assoc. Prof. David Clift, Deakin University, Victoria
Dr. David Druskovich, Central Queensland University, Queensland
Prof. Patrick Garnett, Edith Cowan University, Western Australia
Ms. Jennifer Jones, University of Sydney, New South Wales
Dr. Greg Klease, Central Queensland University, Queensland
Assoc. Prof. David Phillips, Curtin University of Technology, Western Australia

ISBN 1 875902 91 0



Printed by the Central Queensland University Publishing Unit.

# Preface

The Proceedings of the 1998 National Conference of the Chemical Education Division of the Royal Australian Chemical Institute reflect the central role that chemical education plays in providing and serving as a link to theory and practice, to industry, to the community, and to education at the secondary-tertiary interface.
The conference theme, *Bridging the Gap*, was selected in order to focus on the importance of chemical education in a broad societal context. These contexts formed the sub-themes for the conference and were:

*Bridging the Gap between Theory and Practice*
*Bridging the Gap to Industry*
*Bridging the Gap to the Community*
*Bridging the Gap between Secondary and Tertiary*

The Conference Plenary presentation, *Identifying, Bridging and Forever Narrowing the Gap,* by Dr Joe Baker, OBE, not only provided a firm foundation for the conference theme but also spanned the sub-themes in a most stimulating and thought provoking way. In addition, each of the sub-themes was addressed by a number of keynote speakers whose fine contributions further developed the overall conference theme. The success of any conference is the people who make up the event. We acknowledge the conference participants and thank the delegates who gave presentations.
A major goal of the conference was to bring together professionals from all sectors who share an interest in chemical education. The cross fertilisation of ideas between the sectors contributed significantly to the success of the conference.
The conference would not have been possible without sponsorship and we are grateful to the industries and institutions for sponsorship and support.
Finally, the papers in these Proceedings have been fully refereed and we thank the referee committee for the review work undertaken.

David Druskovich and Greg Klease
Central Queensland University, November, 1998.

## Sponsorship and Financial Support

The 1998 National Conference of the Chemical Education Division of the RACI gratefully acknowledge major sponsorship and financial support from:

The Royal Australian Chemical Institute
Central Queensland University

Financial support from the following organisations is also gratefully acknowledged:

Committee for University Teaching and Staff Development (CUTSD)
Boyne Smelters Ltd
Suncor Energy
Orica Australia Pty Ltd
Queensland Alumina Ltd
Queensland Cement Ltd
The Royal Society of Chemistry

## Key to Presentations

The following keys are used in the contents listing, after the paper title, to indicate plenary, keynote and sub-theme presentation:

(a) Bridging the Gap between Theory and Practice
(b) Bridging the Gap to Industry
(c) Bridging the Gap to the Community
(d) Bridging the Gap between Secondary and Tertiary
(K) Keynote
(P) Plenary

# Contents

# IDENTIFYING, BRIDGING AND FOREVER NARROWING THE GAPS

**Joe Baker, OBE**

*Commissioner for the Environment, ACT*
*PO Box 3196, Canberra 2601*

## Introduction

In addressing the aims of the Conference, to give all of us "an enhanced appreciation and understanding of the central role of Chemical Education and of its relevance to all areas of Chemistry", I am forcibly reminded of the central role of the lessons to be learned from the systematic study of chemistry, and of the way that systematic approach has allowed me to link – or bridge – the issues, as we try to understand the challenges of sustainable development, protection of biodiversity, and maintenance of quality of life. We are fortunate in being well-trained to "Bridging the Gap" to generate an educated, informed, and concerned society, and my first thoughts to address the concept of "Identifying, Bridging and Forever Narrowing the Gaps", were quickly modified when I recognised that the "forever" was misplaced.

We must be forever identifying, and forever bridging, as well as forever narrowing the "Gap", because of the always changing nature of the "Gap".

Using the "Bridge" theme, and an image of what constitutes a bridge, this one is indeed challenging – the banks of the river to be bridged are not stable, the flow is varied both on and beneath the bridge, and the nature of the loading on the bridge is comparably varied. So, we are faced with the challenge of building a bridge, forever using it, forever maintaining it in good condition, forever being prepared to modify that bridge for the different types of traffic that will travel on it, or perhaps want to pass over, below, or around it, if our design, maintenance and upkeep are not adequate to meet the perceived needs of all potential users.

In the Periodic Table, the element Carbon has certainly shown the ability to address different challenges, and to come up with a myriad of types of bridges – bonds – to change what may appear to be a position of weakness, (halfway between the two alternative stable arrangements), to be one of paramount significance in the web of life. Dwell on that capability whenever you are faced with a new, perhaps apparently impossible challenge.

Can you reorganize your resources to share, donate, or rearrange to accommodate the needs of others and yet emerge stronger yourself?

The Conference Organizers have specifically designated some obvious gaps to bridge in this Conference

- between the theory and practice of teaching,
- to industry
- to the community, and
- between secondary and tertiary education levels, (and perhaps even between the primary and secondary levels)

I believe that we have to bridge another Gap – that between the inquiring mind and the informed mind, even earlier than the primary level, and that is at the pre-school level. I see one resource to help bridge that gap at the opposite end of the age spectrum, that of the early "chemistry" retirees, who have the benefit of enormous experience and recognition of the need for careful explanation of the questions of the young.

There is also that remarkable bond between the very young and the aged, which continues to enthrall me.

Not all chemist retirees would be suitable, but the available pool becomes larger each year. At another critical step in the preparation scale, there is a clear need to bridge the gap between the "chemistry educated" and the "employment ready" graduate (at all tertiary levels), and we (you and I, the chemistry professionals), face the challenge in society, to bridge the gap to

- elected representatives (at Local, State, and Federal levels), both those in Government and those in other parties; and to
- the general community.

At the "initial level", we have the challenge to

- ensure we are on the bridge of global Chemical Education; and to
- bridge the gap among ourselves.

On this diversity of challenges and opportunities, there will be a diversity of priority Conference outputs and outcomes for each of us, and that, in itself, is a satisfying prospect because of the different principal emphases of our current professional positions, and responsibilities.

Even that is a bridge between past and present, and building to the future, and I encourage you to exercise lateral thought in analyzing how this fascinating topic can better prepare you for your future development.

The Royal Australian Chemical Institute (RACI) is a wonderful vehicle to bridge the gap among qualified Chemists, and, although we must always maintain the professional standards of the Institute, I would love to see an effective method of regularly informing the non-Chemists of what is exciting for them, in the advances in Chemistry. Creating a classification of "Corresponding Members", particularly at local levels, may be one way to build this bridge – or, perhaps, we have to join local service clubs and community groups to bridge the gap, locally. Certainly, one can begin to build a bridge from either side of the gap.

We have to make the general community part of the adventure of discovery and awareness of chemistry in life.

## Being a Chemist

In my Abstract I said, effectively, there is not one thing in this world that is not a chemical or composed of chemicals.

Let us analyze a couple of consequences – perhaps sub-conscious, from the public viewpoint:

(i) "You're a chemist, you must know about that" – no matter what the "that" aspect of Chemistry is;

(ii) "You're a chemist; you're responsible for all those nasty things that are polluting our waters, destroying the ozone layer, causing "El-Nino" and so on.

In practice, the public image of the chemist is not good, and the situation of the 1960's when chemists were seen as producing "good things" is long since gone. I suggest that the reason for this unsatisfactory image may lie – at least in part – with us. As a generalisation, we've been shockingly bad public communicators! This applies at all levels, and we have not attained the skills of the engineer in making decisions on existing knowledge, and maintaining a respected public image.

The challenge of chemists is obviously more diverse than for the engineer, but if in a local community, we have effective bridges among ourselves, we can respond to the difficult questions in a very positive manner. For example, in response to a question one could say "That is a very significant question; my colleague (name) is knowledgeable in that area; I'll arrange, by tomorrow, to let you know when he/she can come with me to talk to you about it".

A response in this form establishes your professional attitude and awareness, and your personal commitment to be the bridge between the enquirer and the knowledgeable person. Both factors will build trust and respect.

I think it was Samuel Johnson who said, "knowledge is of two kinds; that which you have in your memory, and that which you know there to find it". The latter is often more reliable than the former!

More recently, but still a couple of decades ago, the father of a Chinese student of mine told me: "You will succeed if you – know what you know, and know what you don't know, and you will not succeed if you – don't know what you know, and don't know what you don't know." I have tried to live in accord with both of those lessons.

## Experiences in "Bridging the Gap"

My comments are based on my conviction that every living and non-living thing is composed of chemicals, and that chemicals are significant in the regulation of our health and general well being.

On that basis Chemical Education must prepare products as diverse as the greatest:

- chemistry research worker
- chemistry teacher
- homemaker
- managing director
- board member of the largest company.

Certainly you should be as likely to find a successful chemist in the home, or in a business suit, as in a white laboratory coat.

The following examples and opinions have been significant to me in establishing, building, and maintaining bridges to narrow gaps in different situations. I recognize that you may not agree with all my points, but they may represent opportunities for you to identify improvements on my experiences.

(1) To me, teaching is the most important profession, no matter what level the teaching involves – pre-school, primary, secondary, tertiary, or post-tertiary. Therefore, I will always respond positively to a request for assistance from a teacher, and I've always served on School P & Cs, when our children were at school.

(2) At University teaching level, always let the students know (early) that you are interested in them as individuals. Messages can often be best communicated in a light-hearted manner (to suggest to these young people that a Professor may in fact be human). I would often tell a class of "freshers" that I will always wear a tie in the hope that they will at least wear a shirt or a blouse.

Having attracted their attention, I would then inform them that one of my principal objectives in teaching was that, in each class in each year, someone would emerge as "better" than me – a better researcher, a better teacher, a better person – and wherever possible, a better chemist.

No matter how large the class (and they were often around 400 in first-year Chemistry at University of Queensland), it was always my objective to be able to identify each student, correctly, by first name, by the end of term 1. This was essential, in attaining their confidence.

(3) Find out about any limitations of your students. Some may not hear well, some not see well, some may have difficulty understanding our "English", or more likely our "Australian", expression. Also, get to know their interests and their needs. (Those principles apply equally for all types of contacts and interactions.)

(4) Try to be involved in tutorials and laboratory classes in a less formal way than in lectures. Show you enjoy what you are doing!

(5) Remember you are always on display, as a professional, wherever you may be! This applies very much to the way we may speak about other people. It is non-professional to speak negatively about people, in community discussion. There was an old adage "If you can't say anything good about someone, don't say anything". Although the media and politics don't seem to follow this line, I suggest that it is a good guideline for scientists, in the public arena.

(6) Try to be apolitical in your interactions with politicians. Support the elected Government, but keep in touch with "opposition" members. (I dislike the term "opposition", it is immediately confrontationist, and assumes that the parties not in power must oppose whatever the Government proposes. Whereas that may sell newspapers, it does not ensure the best outcomes of Government.)

(7) Tell your story of chemistry with care and conviction – but don't tell people "it is important", it may be "significant", but "importance" has to be a judgement of the listener. My most dramatic lesson in this regard was when I had the opportunity to present a new discovery to our Minister; I began by saying, "Minister, this is the most important discovery we could bring to you". I observed that his eyes showed that he had lost interest, so I stopped and said "Minister, what's wrong?". He replied "Joe, every person that walks through that door tells me that they are here to tell me the most important event or activity, which I must support".

I asked for another chance to tell my story. I recast it to make it personally relevant to his well being, not as a Minister, but as a person, and he became interested, and asked questions. At the end, he said, "that is very important" – and he has never forgotten that discovery.
He, not I, made the decision on importance!

(8) Don't use scientific jargon in interaction with the public – my own research on the substances which give rise to the Royal Purple dye of antiquity is a wonderful example of a story that can be told in very precise technical terminology, or, it can be related in a way that links the study to stories in the Bible, to stories of Greek mythology, and to the Roman emperors. The second method certainly wins high interest. The first leads to early onset of ptosis! (or drooping of the eyelids).

(9) Offer solutions to challenges/problems. If you go to a meeting not supporting a proposal, have an alternative, ready to propose. In Landcare, we found that farmers were eager to grasp solutions to problems, provided they could clearly understand the benefits – for them. The way in which cane-farmers in the wet tropics accepted green cane harvesting and minimum tillage farming, is a classic example of this approach.

(10) Don't wait until you need the contact to make the contact – whether it be with a:
- journalist
- radio or TV presenter
- politician (all 3 levels)
- leader of industry, or a
- funding agency.

Create the linkages (bridges) early, and keep them active by communication of brief high-interest items.

(11) Do not evaluate a lack of an immediate response as a failure to establish a linkage! It may be some time before the target person has a specific issue to address, which brings to mind your exercise.

(12) In everything you see or read, think laterally. "I wonder if 'so-and-so' would be interested in that?", or "Would that be useful for me to illustrate a certain technology", or "Could that be made into a good public interest story?".

(13) Be punctual for meetings! It may be lonely at times, but there is nothing better than being a bit early for a meeting, particularly if the other person is late. The same goes for Committee meetings.

(14) If you are called to a meeting with a decision-maker or industry leader, establish your willingness to help, early on. Even at the "hello" stage, it is a good strategy to ask "How can I help you?", or, if you already know the challenge, say "I think I may be able to work with you to solve this problem".

## Bridging the Gap to Sustainable Development

My education in Chemistry, and the associated systematic approach to problem-solving, have been essential building blocks in my role as Commissioner for the Environment in the ACT. In that role, I am responsible for preparing State of the Environment (SOE) Reports.

We were first challenged to define "the environment", and now have in place in the Environment Protection Act 1997, for the ACT, a definition, which I believe is comprehensive. (see Attachment I). The definition is a result of building a bridge from what I saw as a single paragraph definition to one that is acceptable to a Parliamentary draftsman. It is a new type of bridge, for a chemist to traverse.

At the same time, we have been aware of the development of the National Strategy for Ecologically Sustainable Development (NSESD), and of the need to develop measures (indicators) to assess progress along the pathway to ESD.

It is our belief that, provided the indicators selected for SOE reporting are satisfactory, and that the assessment of the SOE takes into account the interactions and interdependencies, as required in the definition of the Environment, then the SOE Reports are the logical bridges on which to build the assessment of progress towards ESD.

Attachment II shows the stepwise manner in which we take into account the requirements of the definition of the Environment, to produce a SOE Report, and Attachment III is a representation of the way we can bridge the gap to take into account the extra steps which will be necessary to achieve awareness across the whole of community, of what is needed to achieve progress towards ESD.

It is a fully interactive process with numerous bridges to build, maintain, and forever use. It is a process in which chemists have numerous roles – in many of the measures of individual indicators of the condition of the Environment, and in using their systematic approach to problem-solving, to achieve a comprehensive understanding of the State of the Environment, and of the way the Environment is changing over time.

## Concluding Remark

My example of the role I play as Commissioner for the Environment may seem to some as a long bridge from the most fundamental role of Chemical Education in bridging the gaps, but if one analyses my introductory remarks, and the examples I have given in bridging gaps of a wide range of types, it is clear that my training in Chemistry has been critical in providing the professional foundation on which to build towards my current responsibility. Chemistry is an essential factor in life – and a full appreciation of the way in which Chemical Education can be applied to meeting the everyday challenges of professional development could well explain why you are equally likely to find a successful chemist in a business suit as in a white laboratory coat.

# Attachment I

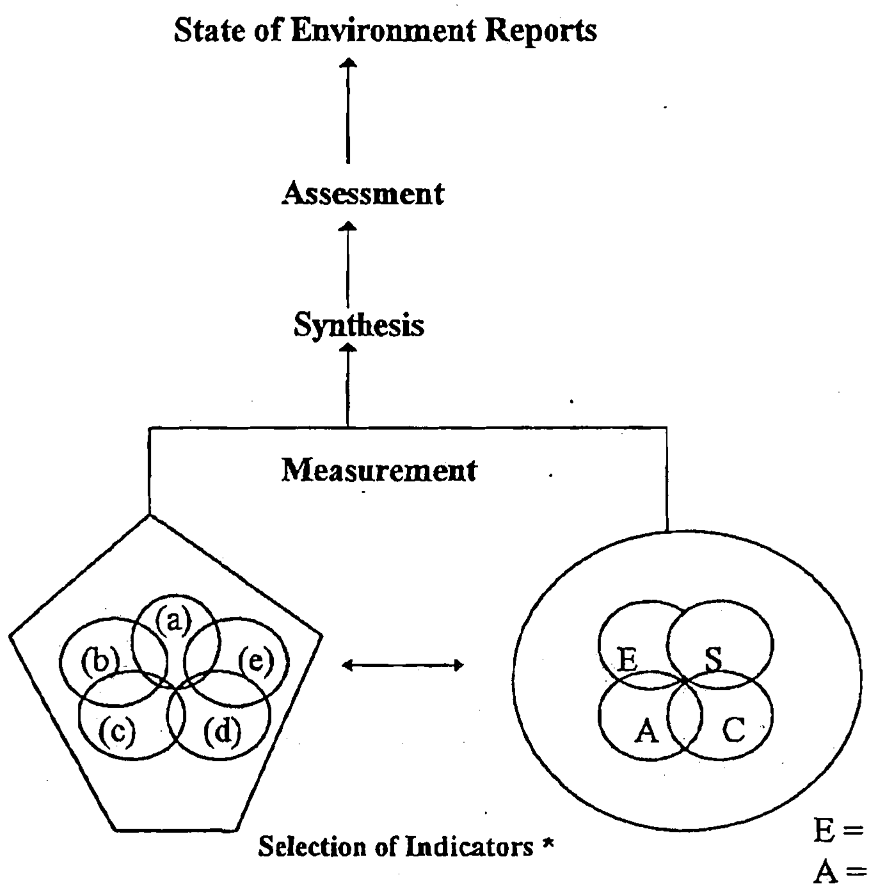
## ACT Environment Protection ACT

### Definition of 'Environment'

(a) the components of the earth, including soil, the atmosphere and water;
(b) any organic or inorganic matter and any living organism;
(c) human made or modified structure and areas;
(d) ecosystems and their constituent parts, including people and communities;
(e) the qualities and characteristics of places and areas that contribute to their biological diversity and ecological integrity, scientific value and amenity;
(f) the interactions and interdependencies within and between the things mentioned in subparagraphs (a) to (e) (inclusive);
(g) the social, aesthetic, cultural and economic conditions that affect, or are affected by, the things mentioned in subparagraphs (a) to (b) (inclusive).

**Attachment II**

# Minimum Requirements for SoE Reporting in the ACT

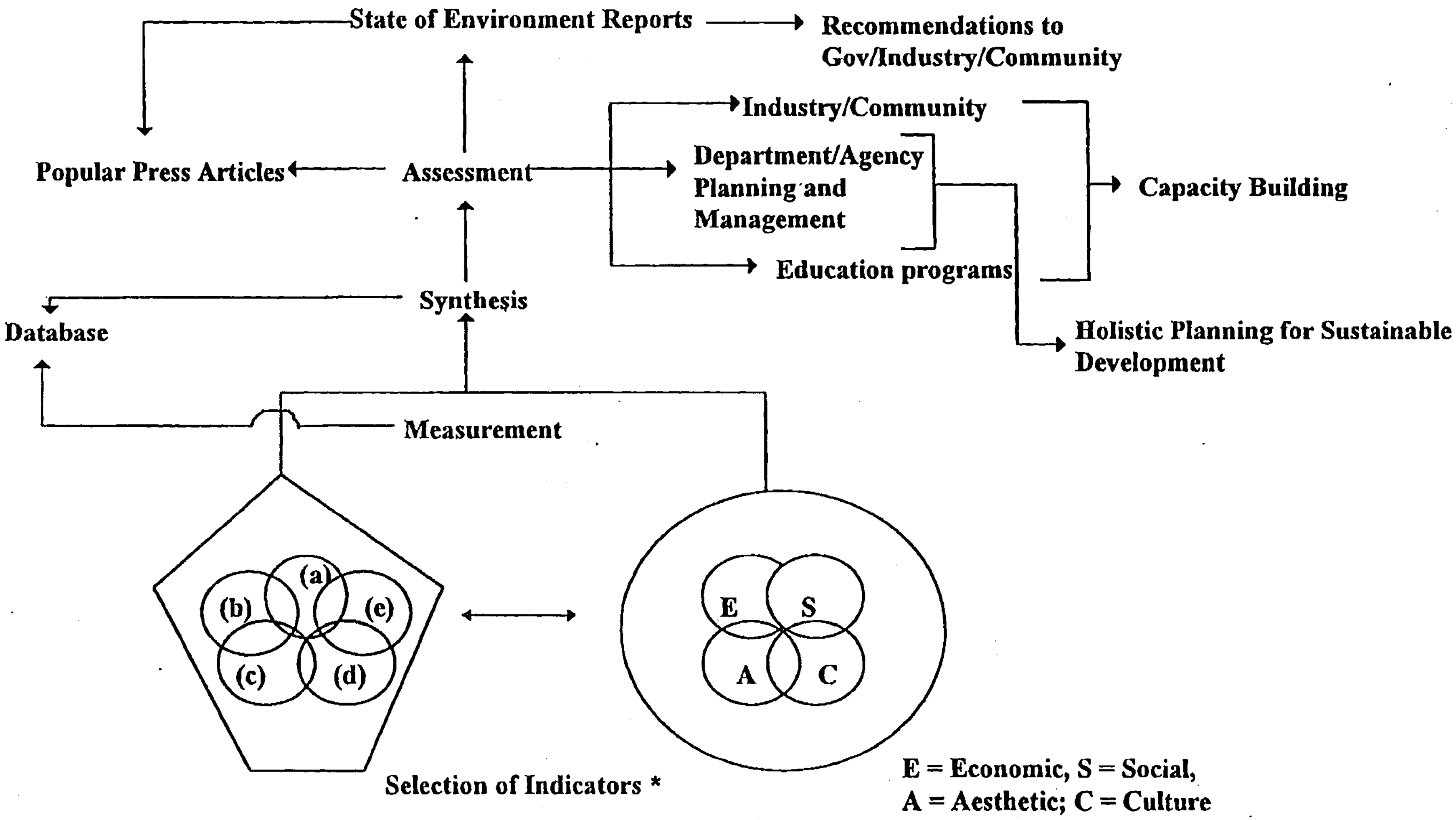



E = Economic, S = Social,
A = Aesthetic; C = Culture

*Indicators may be composite, eg Economic Activity or Specific, eg. Carbon Monoxide Concentration.

Attachment III

# The ideal outputs of SoE Reports




*Indicators may be composite, eg Economic Activity or Specific, eg. Carbon Monoxide Concentration

# BRIDGING THE GAP – ONGOING INTERACTION WITH YOUTH, WITH COMMERCE AND WITH INDUSTRY

**Joe Baker, OBE**

*Commissioner for the Environment, ACT*
*PO Box 3198, Canberra 2601*

## Explanatory Note

This is the second of two plenary lectures, originally prepared as "Bridging the Gap – Ongoing Interaction with Commerce and Industry". In the actual lecture, which was given in Gladstone, some 16 Vacation Course Secondary School students joined the lecture. They had not attended the first lecture, the day before, in Rockhampton, whereas everyone else had done so. For the interest of the students, some parts of the first lecture were discussed again, but in different contexts. "Environment" was again defined, and the interactions and interdependencies incorporated in that definition, highlighted and debated. The challenge of understanding "change" in the condition of the environment was stressed, and the questions asked as to what the audience believed were the major things (or Themes) that people included when they discussed the "Environment"; then given any one Theme, what were the significant Issues within that Theme; and once the Issues were identified, what were the Indicators necessary to identify change in those Issues, and how should each be measured?
The "Condition – Pressure – Response" model for State for the Environment was introduced, and the audience challenged to consider how each person could become involved in understanding and improving the environment, and how this Central Queensland Region, in particular, could become a model of interaction across all sectors of Society, in developing towards and through the 21$^{st}$ Century, in a manner which was sustainable.
Given the significance of coastal activities in the Gladstone-Rockhampton area, the opportunities for sustainable marine development were also included in the presentation, and the audience was encouraged to consider the diversity of job opportunities associated with the sea, particularly with respect to the area of jurisdiction for Australia, under the United Nations Convention on the Law of the Sea (UNCLOS). This area is more than one-and-a-half times the area of the continent and that marine area is small compared with the marine volume in which so many living resources (and some non-living resources) are distributed. The area also includes the sea-bed.

## Introduction

Interaction can be ongoing only if there is reciprocal benefit, mutual respect and a shared need. At a time when public funding of research is diminishing, there is an expectation that commerce and industry will take on this function.
However, we must be realistic.
For commence and industry, there is a clear and unambiguous essential outcome from their activities, and that is an ongoing *economically* profitable operation.
In the first instance, they will support research only if it is clear to them that the research results will improve their economic profitability.

Only at later stage, when they are financially secure, and have trust in our performance, are they likely to offer support for fundamental, or basic, research.
It is essential that we establish the linkages to commerce and industry, at early stages, rather than only when we need to help. They do need our help now, in the drive towards Ecologically Sustainable Development (ESD).
I would like to think that industry and commerce can make a transformation, in time, to an essential *environmentally* profitable outcome – based on the definition of the Environment that I have given.
The significant difference in the two outcomes is that the environmental profitability has measures of social, cultural and aesthetic profitability, as well as that related to the economic outcome. I seek an *environmental rationalist,* rather than an *economic rationalist,* and believe that the chemist can help in that significant shift in objectives. Other sectors of society will also contribute, but the systematic approach of the person educated in chemistry will be a key component.
The challenge is complex; it requires a wise choice among available technologies, and benefit-cost analyses that are much more extensive than simply looking at dollar costs.
We are seeing the social and cultural costs of economic rationalism, - as well as dramatic ecological costs is some types of activities consequent upon economic rationalism decisions – but we are not yet seeing the progressive movement to environmental rationalism.
Somehow we have to find a way to retain the economic profitability, while we build in the other components necessary to achieve environmental profitability.
It will not be achieved in one giant step, but more likely in a series of small steps, with occasional noteworthy gains.
There are many promising signs of mechanisms that will facilitate that process, among which I include State of Environment Reporting, the Intergovernmental Agreement on the Environment, the National Strategy for Ecologically Sustainable Development, the International Standards Organisation (ISO) 9.000 (Quality) and 14,000 (Environment) Series for internationally competitive industries – and for all types of organisations, the National Environment Protection Council (NEPC) and its derived National Environmental Protection Measures (NEPM's), and the Regional Organisations of Local Governments, which are joining together to analyse the holistic attributes of their regions, and to assess the most appropriate types of development to encourage. In industries, in many countries, we now see the absolute requirement for total materials and energy audits – where each company has to record the materials coming in and, in detail, the products coming out, whether they be "waste" or "desired" products.
I put "waste" in inverted commas, because, we as chemists, should be helping to show that "waste" is really the sign of a lazy mind, and that all materials should have a use. In Japan, the materials and energy audit requirements have resulted in many regroupings of industries, so that the "waste" of one operation can be used as a "resource" of another. Can we begin to do that locally?

## Being Aware Globally but Acting Locally

We have to be aware of the developments that are occurring to facilitate international interactions, but, equally, and as for the selection among "available technologies", we must be able to analyse what aspects of that international emphasis will, in fact, benefit the region and the individual. The term "Global Village" has been coined, but

in any village there are the privileged and the underprivileged, and we should be carefully debating all relevant international agreements and arrangements, to ensure that we – as a Nation – do not become the underprivileged.
As one immediate action, have you considered a debate on the General Agreement on Tariffs and Trade (GATT), and its relevance to the objective of moving towards Ecologically Sustainable Development (ESD)?
Such a debate is equally apposite among Year 11 and Year 12 students as it is among professional chemists, and industry and commerce.
These are the types of activities the local Branch of the RACI can facilitate, and thus demonstrate its awareness of issues of relevance to this and future societies.
Successful ESD is going to require such involvement!
The challenges associated with environmentally sustainable commercial and industrial development and profitability, encourage me to propose the establishment of networks around the local Branch of the RACI, where those networks will allow rapid identification and communication of relevant information. Each arm of the network would be a bridge to one sector of society, and the RACI local Branch would be the nucleus which ensured that all those bridges were well maintained.
If in the local Branch, you established a number of coordinators you would, in my experience, be richly rewarded by the interest of the different sectors of society. For example, one could have the following types of coordinators, to:

- maintain a data base of qualified chemistry graduates, and their interests;
- link to secondary schools;
- link to industry;
- link to commerce;
- link to the Local Governments,

in the region.
Such a system should stimulate enhanced employment opportunities, enhanced business and industry success, and enhanced community spirit and quality of life, and enhanced respect for the chemist.
Naturally, one would continue to interact in the way that I proposed in the first of these two lectures!
When I speak of these points, I clearly recall the way in which an RACI member, and Chairman of North Australian Cement, Lew Davies-Graham, stimulated the inauguration of the North Queensland Branch of the RACI in the mid-1960's, how we developed weekend meetings involving students, industry and commerce, how we involved partners in the Saturday night social occasions, and how we made chemistry, very much a part of life. The weekend-meeting model has persisted to this day!
I am pleased to observe that Industry members play a significant part in this meeting and in the local RACI operations.

## Some Specific Talking Points

(i) Employment Opportunities
The theme we have been developing is "Building Bridges". In the sections above, I have stressed the value of networks – which must be relevant, and alive.
Employment opportunities are automatically enhanced when one is aware of existing activities, of new developments, and of the abilities of local candidates.
Although I will give some specific examples, I want you, firstly, to consider the benefits of the Cooperative Research Centre (CRC) Model.

The CRCs were the brain-child of the then Chief Scientist, Professor Ralph Slatyer, who saw the potential benefits of bringing close together, the research workers – Universities and Government Agencies, like CSIRO, ANSTO and AIMS – and the users of the results of research – commerce and industry.
One of the unexpected beneficial outcomes of the CRC operations is that employers become familiar with the abilities of research students in interactive projects, and recognize them as employment prospects. This has removed one of the great barriers to employment – being known to the employer – being more than just another name on a piece of paper.
The network system, suggested above, produces a de-facto CRC environment without the seed funding from Government, and could even spawn specific projects to advance sustainable development in the region.
Obviously, there are wonderful opportunities for new jobs, when one tackles the challenge of removing "waste" from our operations – and from our vocabulary, in the longer term.
One has only to look at the efforts in Japan and in Europe, to appreciate that "waste" is an international issue. Development of local "waste-avoidance" schemes could easily result in opportunities to export this type of technology.
This represents a growth industry.
In the ACT, the Government has developed a proposal to achieve "Zero Waste by 2010". *Attachment I* lists the components of the "Vision" which accompany that proposal. If one studies each part of the Vision, one can identify new challenges – to influence manufacturers, to create new industries, to change society attitudes, etc.
The pessimist will say it is all too difficult; the entrepreneur will see new opportunities – in education, in employment, in commerce and in industry.
The ACT initiative is 100% consistent with the ISO 9,000 and ISO 14,000 series requirements, and these can be adopted equally in industry, in commerce, and in teaching institutions – and in the smallest and the largest organisations.
Can it be initiated locally? Obviously, I believe it can!
Another great employment potential is that associated with the sea.
It is not so long ago – and it may well still be the case in many societies – that if you said you wanted to work in marine fields, the reaction would be "You must be a marine biologist". I want to deliberately ridicule such narrow thinking!
There is no type of job "in the terrestrial sphere" that is not comparably applicable "in the marine sphere"!
*Attachment II* lists certain classifications of marine study areas that one may expect to see as available in University curricula. *Attachment III* shows the employment opportunities and or fields of specialisation that could be derived from such studies.
There are rich employment opportunities in all these fields, but if one asked me what I saw as immediate urgent needs, they would be in the fields of "Law of the Sea" and "Marine Veterinary Science".
However all the fields are relevant to Australia's challenge to have in place by 2004, satisfactory management practices to show that it can sustainably manage the living and non-living resources of its vast marine area of jurisdictional responsibility, afforded by the UNCLOS.
*Attachment IV* shows the extent of this "new" area of responsibility.

(ii) New Commerce and Industry Opportunities

What some may see as a constraint, others will see as opportunity.

The examples above, of new employment opportunities are equally valid as new business opportunities. The ACT Vision on Waste specifically addresses the need to develop new industries, and this has already occurred in Canberra.

The marine sphere of activity is one where Australia has already shown its ability to develop a range of industries, e.g. specialist boat-building in Tasmania, specialist oceanographic instrumentation in Western Australia, aquaculture of several types throughout Australia- tuna in South Australia, Atlantic salmon in Tasmania, blue mussels in Victoria, prawns in New South Wales, Queensland, and Northern Territory – to name a few, reef tourism in Queensland, and Western Australia – including teams of young graduates who have set themselves up as tour guides.

These are but a few of what has already emerged in the past decade.

But what of the future, and what of this Central Queensland Region?

The Fitzroy River is one of Australia's major rivers, and water is going to be a resource which will determine what industries can be sustainably maintained in different parts of Australia. I suspect that we cannot, in the future, see dams as the best way to store water. The evaporation rate is far too high in our climate which features long periods of hot, dry conditions.

We need inventive ways to store water. What ideas do you have?

Central Queensland already has a strong primary industries base, and a strong educational and research institution structure. Are those factors well integrated to ensure that we are analysing every opportunity to derive value-added products from our primary produce?

Do we have the people trained in international Laws, and in international trade to take advantage of new opportunities which may arise through those factors?

Wherever I look, I see opportunities, but they all seem to have one feature – no one can be implemented without cross-fertilisation of ideas and awareness.

Inevitably, the situation brings me back to the opportunities that can be identified and realised through networks – which the RACI is qualified to initiate – and through CRC-type arrangements. Earlier on, I also spoke about the significance of ISO 9,000 (quality) and ISO 14,000 (environment) series, which are a basis for implementation of best management practices, no matter what your business. There are groups that have established operations to explain and to assess progress against these international standards, and I suspect that many of the successful places of business in the Central Queensland Region have already adopted ISO 9,000 – but perhaps not yet ISO 14,000.

It may be timely to initiate a forum on the ISO 14,000 series and their impact.

Value-adding of products and targeting niche markets have already been features of recent successful Australian business ventures.

Australian native plants offer spectacular opportunities for both distinctive value-added products, and for niche market entry.

Marine species have been little exploited, except for direct food value, (and for their tourist appeal), and the marine sphere remains open for groups willing to observe and to think laterally for new business opportunities.

Gladstone itself almost demands consideration of industries based on waste-avoidance, as it emerges as a – if not the – major centre of industrial development, outside of Brisbane.

## Concluding Remarks

Today, I look at an audience that represents the present and is primed for the future. We have an ideal mix of students, teachers, researchers and leaders of commerce and industry. If we can build the bridges to maintain and forever facilitate and strengthen the links among us, we can build a society capable of meeting challenges and dealing with change, while minimising any adverse effects that may impact on our quality of life.

This is an era of change, but it is also an era in which local communities and regions should evaluate the opportunities and technologies available, weigh them against your specific social, cultural, and aesthetic requirements, and select those most appropriate to your own priority directions towards sustainable development. This is a good year to put networks and planned interactions in place. The devolution of responsibility for Agenda 21 implementation to Local Government – and for many other functions – will make Local Government, and groups of Local Governments, more significant in developing plans for sustainable development, consistent with the objectives of the State's Integrated Planning Act. The year 2002 will see the next assessment of how the world is progressing towards sustainable development, in "The Rio+10" Conference. It would be nice to think that Queensland, and particularly Central Queensland, could show leadership in demonstrating that planned and integrated sustainable development can be economically, socially, culturally, and aesthetically – that is, environmentally, achieved.

The RACI can facilitate the realisation of this leadership potential.

You can all be part of the *Network* to achieve it.

## Attachment 1

## THE VISION

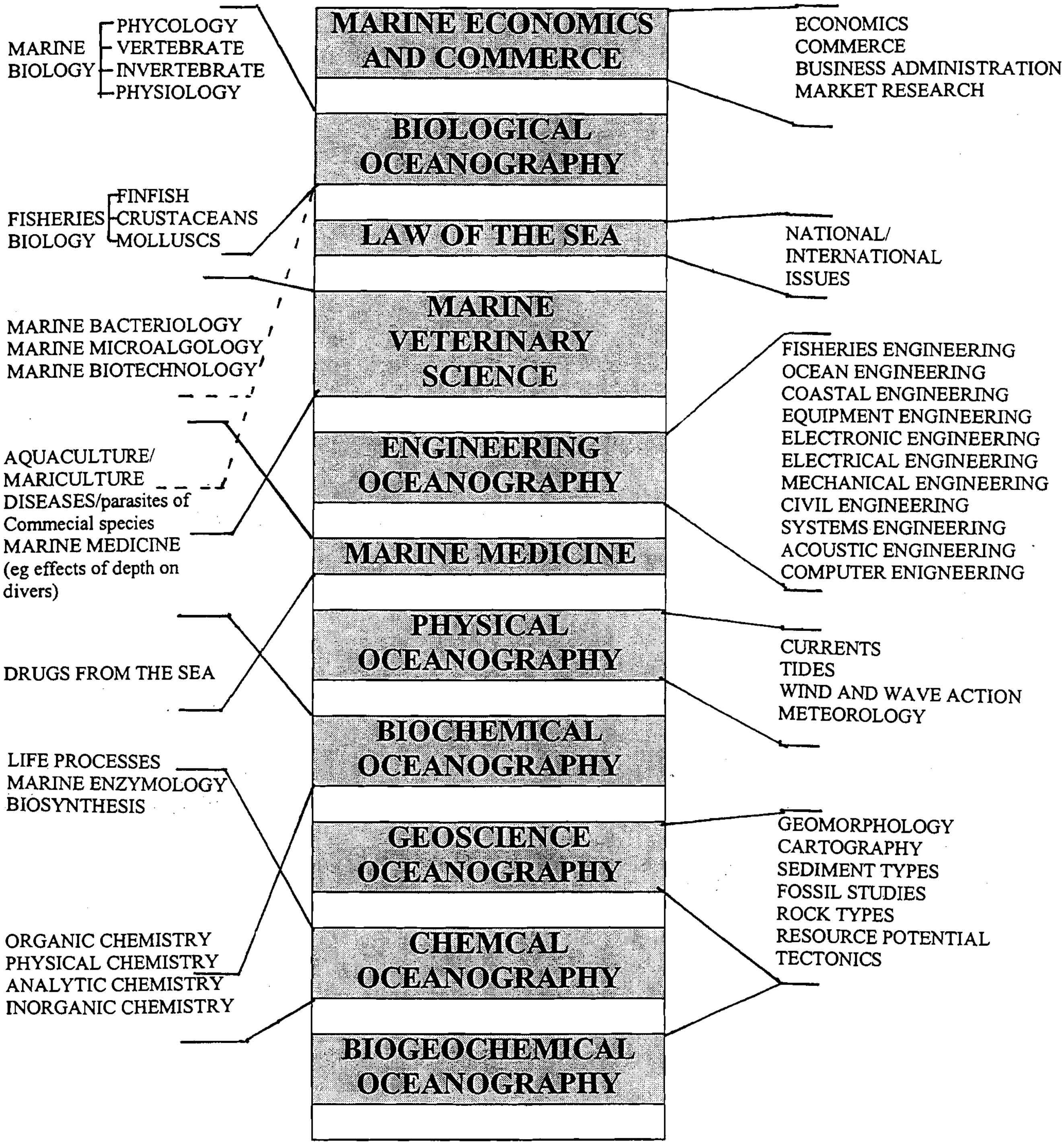
By 2010 it is envisaged that waste will have been eliminated by a community that:

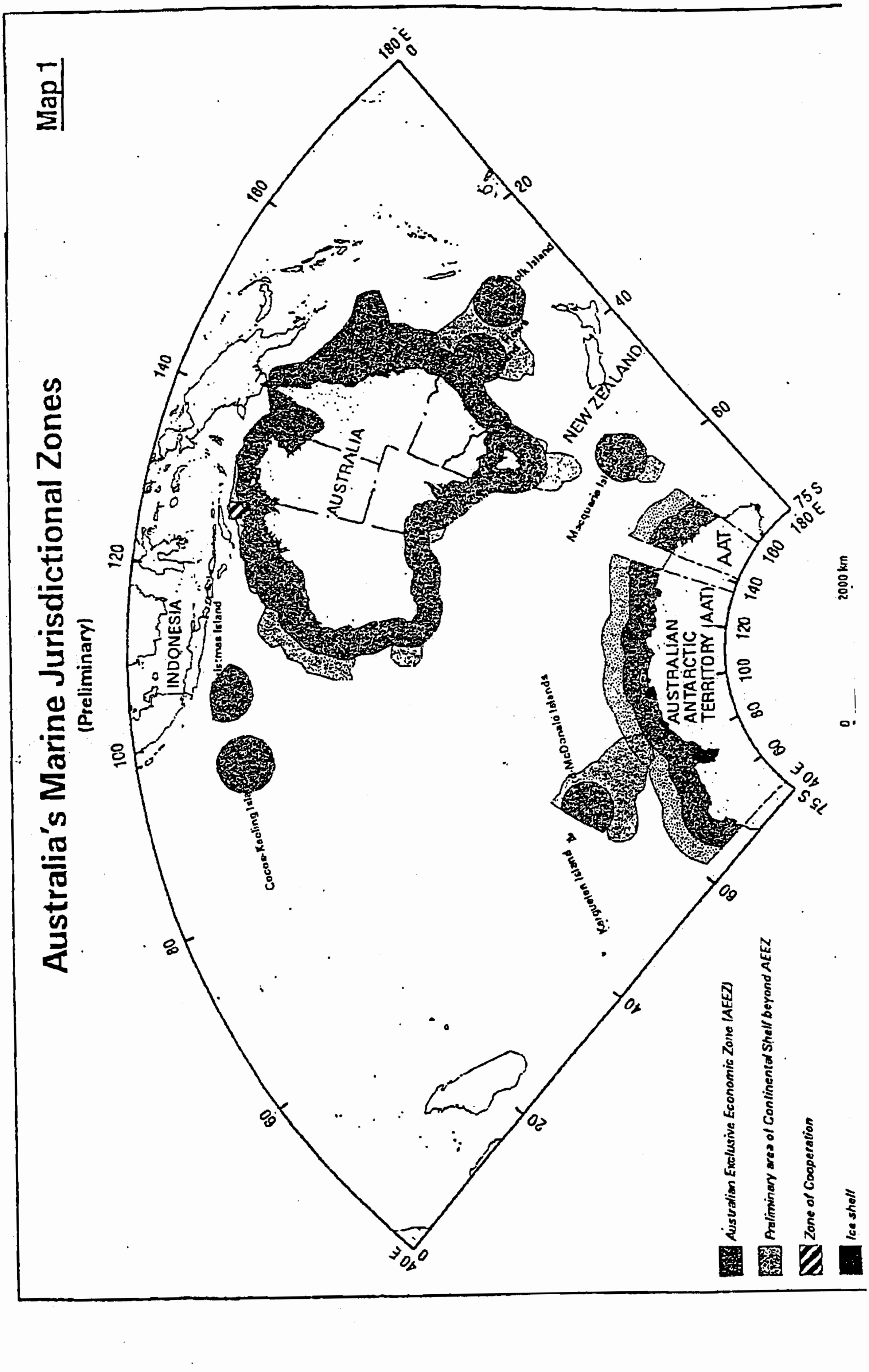
- has encouraged the producers of goods to take responsibility for the form in which their products are sold to ensure that waste is not generated with the initial production, during use or at the end of the product's life;
- has created an environment for developing innovative solutions to avoid generating waste;
- only buys what it needs. Whether they be building materials or groceries, waste is avoided by efficient buying and production practices;
- has created cost-effective methods for recovering resources so that materials can either be re-used or reprocessed into valuable products;
- has created industries dealing in unwanted materials;
- has extended the opportunities for resource recovery to the Canberra region; and
- takes pride in its achievements in eliminating waste and includes environmental education as a key element in achieving the vision.

**Attachment II**

| |
|---|
| MARINE ECONOMICS AND COMMERCE |
| |
| BIOLOGICAL OCEANOGRAPHY |
| |
| LAW OF THE SEA |
| |
| MARINE VETERINARY SCIENCE |
| |
| ENGINEERING OCEANOGRAPHY |
| |
| MARINE MEDICINE |
| |
| PHYSICAL OCEANOGRAPHY |
| |
| BIOCHEMICAL OCEANOGRAPHY |
| |
| GEOSCIENCE OCEANOGRAPHY |
| |
| CHEMCAL OCEANOGRAPHY |
| |
| BIOGEOCHEMICAL OCEANOGRAPHY |
| |

## Attachment III




Map 1
Australia's Marine Jurisdictional Zones
(Preliminary)
INDONESIA
AUSTRALIA
NEW ZEALAND
AUSTRALIAN ANTARCTIC TERRITORY (AAT)
AAT
Cocos-Keeling Islands
McDonald Islands
Kerguelen Island
Macquarie Isl
2000 km
Australian Exclusive Economic Zone (AEEZ)
Preliminary area of Continental Shelf beyond AEEZ
Zone of Cooperation
Ice shelf

# PEDAGOGICAL CONTENT KNOWLEDGE: BRIDGING THE GAP BETWEEN EDUCATIONAL THEORIES AND TEACHING CHEMISTRY

**Robert Bucat**

*Department of Chemistry, The University of Western Australia*

## Abstract

High quality teaching demands more than both good content knowledge and good pedagogical knowledge: it requires a consideration of how specific characteristics of the content might influence one's pedagogy, and vice versa. The term *pedagogical content knowledge* refers to knowledge derived from the interaction between pedagogical beliefs and characteristics of the content in order to decide how a particular topic might be presented for optimal "learnability". To use an example in our context, pedagogical content knowledge refers not to knowledge about stereochemistry, but to knowledge about the teaching and learning of stereochemistry. Perhaps reflection upon, and research into, pedagogical content knowledge will be the next major step in the evolution of chemical education.

Attention is given to an analysis of pedagogical content knowledge specific to a particular topic in chemistry, and how this might influence the teaching of that topic.

It is argued that developing pedagogical content knowledge about topic X constitutes the creation of new knowledge different from, but equally as worthy as, research knowledge about topic X. Recognition of this might enhance the status of good chemistry teachers.

## Introduction

It is my perception that the chemical education enterprise has traversed two distinct phases over recent decades: a reflective phase and, more latterly, a research-based phase. Currently it seems not sure of its identity and where it should go. If we accept a distinction between *pure* and *applied* in chemistry research, then I suggest by analogy that we have been intensively engaged in pure chemical education research in recent years. Perhaps the time is ripe to engage in a line of applied research, involving both reflective analysis and empirical studies, the findings of which will be immediately useful to the teacher at both secondary and tertiary levels. When we have bridged the gap between general educational theoretical advances, and specific knowledge that can assist us to teach about chemical equilibrium (for example), then perhaps chemical education research will begin to make more impact on the practice of teaching chemistry. This applied research will necessarily involve collaboration between chemists and teachers, along with science education researchers.

## Chemical education, Stage 1: Reflection about "What to teach?"

Until about 1975, there was very little experimental research concerning the chemistry curriculum. Chemical education was concerned almost exclusively with either (i) advances in the subject matter, or (ii) the question "What should be included in the chemistry curriculum?" Almost every issue of the *Journal of Chemical Education* contained articles related to this latter question. The powerful influences in chemical education were position papers published by highly respected academic chemists. These papers were based on opinion and judgement derived, not from empirical findings, but from reflection grounded in experience and wisdom.

These position papers seem to suggest that the "answer" for chemical education lay in the selection or design of the "right" curriculum, as defined by the choice of subject matter. In most (but not all) of these discussions, it seems as though the curriculum is perceived as an interaction between teacher and subject matter. It was as though the students were regarded as part of the fixtures (or the teacher's context?) in the teaching task - especially at the tertiary level.

**Chemical education, Stage 2: Experimental research into "What is learned?"**

From about 1975 we have seen a dramatic change in the nature of the science education endeavour. Although we still need to, and do, ask the question "What should be taught?" there has been an enormous investment of energy in experimental research into the question "What is learned?" The world has been tipped upside down! The focus has shifted from the curriculum (the syllabus to be taught) to the student, reflection has given way to experimental investigation, and those asking the questions are mostly "science educators" rather than scientists. In a few instances around the world, people engaged in this research are in Chemistry Departments, doing chemistry and working with chemists.

Probing students' understandings became a science education "industry" and there is at least one book (White & Gunstone, 1992) describing methods for going about this very difficult task. Much of this research is described as "misconceptions research": its purpose has been to identify inadequacies in students' understandings, in comparison with what the teachers might have hoped for. Garnett et al. (1995) and Nakhleh (1992) have published comprehensive reviews of the findings of "misconceptions research" in chemistry education.

There are two stunning outcomes from the very many "misconceptions research" studies that have been conducted. Firstly, many of the misconceptions that have been identified are common to students of all countries, and at a variety of levels of education, including many students scoring well in formal written examinations. Secondly, many misconceptions are extraordinarily resistant to change.

These findings have led to questioning of the "transmission" (teaching is telling and learning is remembering) mode of teaching. The evidence supports the view that formal learning often constitutes little more than an ability to reproduce symbols and words and to apply algorithms. And so began (or, perhaps better, re-convened) a period of reflection upon how people learn. If transmission of knowledge by telling is not a very effective way of teaching and learning, why isn't it? What is a better way? This is a story in itself and is not the issue here, but perhaps I might refer to two lines of thinking.

Firstly, we have had ten or fifteen years on top of a wave called "constructivist" theory. The essence of constructivism is perhaps best summarised as: "Knowledge is constructed in [not absorbed by] the mind of the learner" (Bodner, 1986). By and large, a "constructivist" teacher will value and take into account the students' prior understandings, will look for ways to develop linkages between new knowledge and pre-existing sound student knowledge, and might try to create situations such that the students need to grapple with challenging ideas.

Secondly, an "Information Processing model" (Johnstone, 1997) has at its heart (i) a selective filtration process, influenced by what we already know, for choosing which of the incoming sensory signals we attend to, and (ii) an interaction in a limited capacity "working memory space" between selected new information and prior knowledge.

**Where are we at?**

For researchers, the belief that teachers' conceptual understandings can be transferred in 1: 1 correspondence to students through "teaching by telling" is dead and buried. But it must be said that praxis consistent with the transmission model is still alive and kicking. The research-practice gap has not been bridged.

Here we are in 1998 with an encyclopedic collection of student "misconceptions" and an enhanced knowledge of the conditions for effective learning, based upon which a range of student-centred teaching methodologies, such as cooperative learning, have become fashionable. Mitchell and Mitchell (1992) have published a valuable typology of classroom strategies designed to provoke conceptual struggle, and Bucat and Shand (1996) have developed examples of these in a few chemistry topics.

But there is a partial vacuum. We have new generic ideas about teaching, but little guidance as to how each teacher might apply these to the teaching of particular chemistry topics. We have a multitude of research publications concerned with identification of misconceptions, but usually no more than bland, general statements about preventative or curative actions - such as "We must find out what the students know at the start and use that as the basis for our teaching.". We have educational researchers and teachers working in isolation from each other - except in a few cases of teachers involved in "action research". We have science education researchers and academic chemists by and large distant from each other and even exhibiting some disdain for each other. And, perhaps as a consequence of all of the above, educational research has had little impact on science teaching except in particular instances. Finally, it seems to me that many people involved in science education research are asking "Where to now?"

**Chemical education - the future: Pedagogical content knowledge.**

Science education research has important messages for the teaching and learning of chemistry, but I wonder if the focus is not too much on advancement, rather than application, of generic educational theories. Commenting on criteria used for evaluation of teaching in the 1980s, Shulman (1986) asked "Where did the subject matter go? What happened to the content?" Of course we should attempt to advance educational theory, in the same way that any other discipline does "pure research". But surely advances in theory of a discipline have only one purpose: to reflect back on, and improve, the practice of that discipline. Is the time ripe to think through what we now know about student learning, in conjunction with analysis of what it means to understand particular concepts in science, to generate useful pedagogical practices specifically tailored for each concept? And then to assess, through research, the effectiveness of these practices? This would correspond with the notion of "applied research" in the science disciplines.

A clue to the future is in the following excerpt (Fensham & Kass, 1988):

> There are two primary and interacting sources of events in chemistry instruction that can lead to inconsistency, or discrepancy for its learners .......... . The first is the science of chemistry itself. The second is the teaching of chemistry. ........... . The interaction between these two sources is obvious, but it is often ignored in the education of chemistry teachers.

Perhaps a productive path for us to travel is what Shulman (1986) has labelled *pedagogical content knowledge* (PCK). While *content knowledge* refers to one's understanding of the subject matter, and *pedagogical knowledge* refers to one's understanding of teaching and learning processes independent of subject matter, *pedagogical content knowledge* refers to knowledge about the teaching and learning of particular subject matter, taking into account its particular learning demands.

The rationale for doing this is aptly put by Geddis (1993):

> The outstanding teacher is not simply a 'teacher', but rather a 'history teacher', a 'chemistry teacher', or an 'English teacher'. While in some sense there are generic teaching skills, many of the pedagogical skills of the outstanding teacher are content-specific. Beginning teachers need to learn not just 'how to teach', but rather 'how to teach electricity', how to teach world history', or 'how to teach fractions'. (p. 675)

Or, 'how to teach stoichiometry', or 'how to teach chemical equilibrium', or 'how to teach stereochemistry". Obviously the demands of learning about stoichiometry are different from the demands of learning about stereochemistry. Good teachers analyse (with varying degrees of consciousness) the various sorts of content-specific demands.

Each chemistry teacher has a unique knowledge of chemistry. We cannot hope to transmit to the students a duplicate of this knowledge. The teacher's job is to re-package and re-present his/her knowledge in such a way that gives the students some hope of achieving the understandings that we hope for. The re-packaging task will depend upon the nature of the subject matter. And so we teachers have to come to know the subject matter, not only for itself, but also in terms of its teachability and learnability. This task has been conceptualised (Shulman, 1986) as "transformation of subject-matter knowledge into forms accessible to the students". Geddis (1993) points out:

> In order to be able to transform subject matter content knowledge into a form accessible to students, teachers need to know a multitude of particular things about the content that are relevant to its teachability. (p. 676)

Developing ways to do this is indeed the creation of new knowledge of a type that characterises the good teacher and is part of his/her professional skill. The requirement for teachers to invent this new knowledge should be recognised. The highest levels of teaching ability demand more than just common sense.

**What constitutes pedagogical content knowledge?**

It seems to me that a prerequisite to generating PCK about a given topic is an analysis of the "sorts of knowing" that will enrich one's understanding of that topic. In relation to single-component phase diagrams, West and Fensham (1979) have identified a highly interlinked relationship amongst propositional knowledge, intellectual skills and images of observable phenomena. Let's consider just a few 'sorts of knowing', other than propositional knowledge and intellectual skills, in relation to the topic of chemical equilibrium (just to provide a concrete example). Awareness of these constitutes PCK:

1. White (1988, p.31) has remarked on the importance of images of observed phenomena and experiences, to which he attributes the label *episodes*. What episodes might enrich a student's understanding of chemical equilibrium? In what senses could each episode lead to richer understanding?

2. We have become increasingly aware, as discussed by Johnstone (1991), of the learning difficulty presented by the need to consciously switch between observable macroscopic phenomena and images of the sub-microscopic molecular level - which we use to rationalise macroscopic behaviour. Bent (1984) has written in fascinating terms about

"seeing through the eyes of a chemist". Ben-Zvi et al. (1987) have demonstrated the importance of also recognising the distinction between single-molecule sub-microscopic imagery (eg, for dipole moments) and multiple-particle images (eg, for limiting-reagent stoichiometry). What are the characteristics of "good" mental imagery for the topic of chemical equilibrium? Could some mental models have features which would handicap quality learning?

3. One component of richness of understanding chemistry is an ability to properly use and interpret the language that chemists use (Cassels & Johnstone, 1983; Sutton, 1992). Categories of language that can provide difficulties for meaningful communication include (i) chemical symbolism, such as symbols, formulas and equations, (ii) mathematical statements, (iii) technical jargon peculiar to the field, (iv) words which are also used in everyday settings, perhaps with different meanings, and (v) oddities, that might be called chemical colloquialism. The topic of chemical equilibrium is loaded with linguistic traps for students. What are these potential traps? What strategies might be used to avoid mis-communication, or to avoid rote uncomprehending use of the language, in the topic of chemical equilbrium?

4. The more easily one can operate with a variety of models, or multiple levels of explanation, the richer is one's understanding of a subject. Carr (1984) has pointed out that multiple models of acids and bases can be a source of confusion for students. Are there multiple levels of explanation applicable to the topic of chemical equilibrium? What are the inclusivity/exclusivity relationships amongst them? What are the limitations of applicability of each? Which are appropriate for your students? Why?

5. In the first conference in this series nineteen years ago, West and Fensham (1979) suggested that awareness of the linkages between ideas, skills and episodes is important to quality learning of chemistry. We might add mental images to this list. And we might also argue that recognition of the (extrinsic) links between the topic under study and other chemistry topics can enrich our understanding. What intrinsic links are important for an understanding of the topic of chemical equilibrium? What extrinsic links show the place of equilibrium in the discipline of chemistry, and in the world of science? How might we help students to realise these links and to appreciate their importance?

6. Other components of PCK for any given topic include recognition of the scientists' sources of knowledge (why we believe what we believe), an ability to distinguish between what is demonstrable knowledge and what is arbitrarily decided knowledge, and what the scientific community still does not know about the subject.

In addition, a teacher with good PCK will know what chemistry education research has to say about students' understandings of the subject. What do students find difficult, and what is not so difficult? What is the source of the difficulties? What misconceptions are common? What recommendations are made for avoiding or "curing" them?

Such a teacher would also have an acute awareness of the tension that may exist between attempts to simplify the subject matter for immediate "learnability" and either veracity or long-term teaching goals. Hawkes (1995; 1996) publishes regularly in the *Journal of Chemical Education* on this issue.

To achieve the sorts of understandings identified above, a teacher might have a vast store of PCK in the form of a repertoire of teaching strategies to call upon as appropriate - including analogies, laboratory experiments, classroom demonstrations, concept mapping tasks, Venn diagram tasks, assignments, or projects. And this teacher will understand the specific purposes of each of these strategies, their strengths and weaknesses, and the appropriate moment to use each of them.

I believe that the "pedagogical-content knowledgable" teacher is better placed than otherwise to make sound choices between alternative courses of action, based on content-specific reasoning, in order to maximise richness of learning. Of course one needs to recognise that classroom decisions cannot be made entirely on content-specific grounds. Any teacher will, with some degree of consciousness, take into account his/her educational philosophy, system constraints, colleague support, colleague constraints, and understanding of the motivations and the abilities of the students.

Again I point to the incredibly diverse and demanding range of skills needed for good teaching. Are these any less, in terms of difficulty of acquisition or responsibility of administration, than the skills of lawyers, sharebrokers, politicians or research chemists?

**Where to?**

In the teaching profession the accumulated PCK of each of its participants grows with experience, peaks at retirement, and then disappears - often with hardly a contribution to the collective wisdom of the profession. What other profession would accept this state of affairs? While in other professions, successive standard-bearers "stand on the shoulders of giants who came before them", the teaching profession seems to be engaged in many-fold "re-inventions of the wheel". I recommend two courses of action:

1. For each topic in chemistry, teachers, chemists and chemistry education researchers should work together, integrating pedagogy, chemistry and research findings, to systematically create and document a pool of PCK. I do not envisage that this collection of PCK should be prescriptive. The collection might, however, constitute a research-based resource pool of notes, ideas and strategies relevant to the teaching and learning of the subject matter, into which all chemistry teachers might dip.

   There are, of course, already a myriad of teaching tips and discussions to be found about the teaching of particular topics dispersed throughout the science education literature. But there is not a systematic collection of these, with evaluations and comparisons. Furthermore, I believe that recent research findings and yet-to-be-done analyses of the particular demands of understanding particular topics, will lead to new PCK.

2. Architects, chess players and lawyers can learn from documented case studies that exhibit the philosophies and skills of masters in their field, indicating their "game plans", their strategies, tactics, and responses to particular problems and situations. Wouldn't chemistry teaching benefit from research which provided detailed case studies of master teachers teaching about chemical equilibrium, for example? This "applied research" (in the sense that it is not necessarily directed at extending theory, but attempting to provide insights into real problems) would not only describe the master teacher's actions, but also probe his/her thought processes at critical points during a course, and track the changing understandings and perceptions of the students.

   There are previous reports of observations, akin to case studies, of teachers' use of content knowedge in the classroom (Garnett, 1987; Munby & Russell, 1992; Wilson, Shulman, & Richert, 1987), but in these the subject matter has been merely the vehicle for making interpretations about the generic nature of teacher knowledge. The moment seems to be crying out for studies which, in the light of these generic characterisations, observe, interpret and evaluate the PCK used by particular teachers in instruction of a particular topic, *to illuminate the teaching of that topic, rather than to illuminate teaching in some generic sense.* In a word, it would be useful to know "what works" in terms of specific content-related decisions, for master teachers.

There already have been exploratory attempts to describe pedagogical content knowledge pertaining to particular chemistry topics. Examples include those by Geddis et al. (1993), Magnusson and Krajcik (1993), and De Jong et al. (1995) which refer, respectively, to the content-related demands of teaching about the topics of isotopes, thermodynamics and oxidation-reduction chemistry. Hopefully these represent the beginning of an accumulation of such analyses, which would be extremely useful for both the pre-service education and the professional development of chemistry teachers. And they might even be useful resources for chemistry students - especially those at the tertiary level.

## References


Bent, H. A. (1984). Uses (and abuses) of models in teaching chemistry. *Journal of Chemical Education, 61*(9), 774-777.

Ben-Zvi, R., Eylon, B.-S., & Silberstein, J. (1987). Students' visualisation of a chemical reaction. *Education in Chemistry, 24*(4), 117-120, 109.

Bodner, G. (1986). Constructivism: A theory of knowledge. *Journal of Chemical Education, 63*(10), 873-878.

Bucat, B., & Shand, T. (1996). *Thinking Tasks in Chemistry: Teaching for Understanding*: Department of Chemistry, The University of Western Australia.

Carr, M. (1984). Model confusion in chemistry. *Research in Science Education, 14*, 97-103.

Cassels, J. R. T., & Johnstone, A. H. (1983). The meaning of words and the teaching of chemistry. *Education in chemistry, 20*(1), 10-11.

De Jong, O., Acampo, J., & Verdonk, A. (1995). Problems in teaching the topic of redox reactions: Actions and conceptions of chemistry teachers. *Journal of Research in Science Teaching, 32*(10), 1097-1110.

Fensham, P. J., & Kass, H. (1988). Inconsistent or discrepant events in science instruction. *Studies in Science Education, 15*, 1-16.

Garnett, P. J. (1987). Teaching for understanding: Exemplary practice in high school chemistry. In K. Tobin & B. J. Fraser (Eds.), *Exemplary Practice in Science and Mathematics Education.* (pp. 45-58). Perth: Science and Mathematics Education Centre, Curtin University.

Garnett, P. J., Garnett, P. J., & Hackling, M. W. (1995). Students alternative conceptions in chemistry: A review of research and implications for teaching and learning. *Studies in Science Education, 25*, 69-95.

Geddis, A. N. (1993). Transforming subject-matter knowledge: The role of pedagogical content knowledge in learning to reflect on teaching. *International Journal of Science Education, 15*(6), 673-683.

Geddis, A. N., Onslow, B., Beynon, C., & Oesch, J. (1993). Transforming content knowledge: Learning to teach about isotopes. *Science Education, 77*(6), 575-591.

Hawkes, S., J. (1995). pKw is almost never 14.0: Contribution from the Task Force on the general chemistry curriculum. *Journal of Chemical Education, 72*(9), 799-802.

Hawkes, S. J. (1996). Salts are mostly NOT ionized. *Journal of Chemical Education, 73*(5), 421-423.

Johnstone, A. H. (1991). Why is science difficult to learn? Things are seldom what they seem. *Journal of Computer Assisted Learning, 7*, 75-83.

Johnstone, A. H. (1997). Chemistry teaching - science or alchemy? *Journal of Chemical Education, 74*(3), 262-268.

Magnusson, S., & Krajcik, J. S. (1993). *Teacher knowledge and representation of content in instruction about heat energy and temperature.* Paper presented at the Annual Meeting of the National Association for Research in Science Teaching., Atlanta.

Mitchell, J., & Mitchell, I. (1992). Some classroom procedures. In J. R. Baird & J. R. Northfield (Eds.), *Learning from the PEEL Experience* (pp. 210-268). Melbourne: J. R. Baird and J. R. Northfield, Facultyof Education, Monash University.

Munby, H., & Russell, T. (1992). Transforming chemistry research into chemistry teaching: The complexities of adopting new frames for experience. In T. Russell & H. Munby (Eds.), *Teachers and Teaching: From Classroom to Reflection* (pp. 90-108). London, New York, Philadelphia: The Falmer Press.

Nakhleh, M. B. (1992). Why some students don't learn chemistry: Chemical misconceptions. *Journal of Chemical Education, 69*(3), 191-196.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Resarcher, 15*(2), 4-14.

Sutton, C. (1992). *Words, science and learning*: Open University Press.

West, L. H. T., & Fensham, P. J. (1979). *What is learning in chemistry?* Paper presented at the Chemical education: A view across the secondary-tertiary interface., Gippsland Institute of Advanced Education.

White, R., & Gunstone, R. (1992). *Probing Understanding*: The Falmer Press.

White, R. T. (1988). *Learning Science*: Blackwell.

Wilson, S. M., Shulman, L. S., & Richert, A. E. (1987). '150 Different ways of knowing: Representations of knowledge in teaching. In J. Calderhead (Ed.), *Exploring Teachers' Thinking.* (pp. 104-124). London: Cassell.

# USING THE CABLE NETWORK TO TEACH CHEMISTRY OFF-CAMPUS

**David Clift**

*School of Biological and Chemical Sciences, Deakin University, 662 Blackburn Road, Clayton, Victoria, 3168.*

**Abstract**

During the past eighteen months first year chemistry units offered by the Rusden campus of Deakin University have been broadcast live throughout Melbourne on the Optus Education channel. This has not only provided a service to the University's on-campus students, but it has made these units accessible to all subscribers to the Optus cable network in Victoria and interstate. This situation arose because of the necessity to deliver the first year unit *Foundations of Chemistry* on two of the University's metropolitan campuses in 1997. This paper will describe how this was done and the impact that it has had upon course delivery.

## Introduction

*Foundations of Chemistry* has been taught successfully on the Rusden campus of Deakin University or its predecessor institutions for 25 years. It has enabled hundreds of students with no background in chemistry to proceed to more advanced studies in the discipline. In recent years, the unit has drawn students mainly from the School of Biological and Chemical Sciences, though there are also some from other schools within and outside the Faculty of Science and Technology.

In 1997, it was proposed that the unit be offered on the Burwood campus for the first time as a service to students in the Faculty of Health and Behavioural Sciences. In order for this to occur, either the lecturer had to travel to repeat a lecture that had already been delivered on the Rusden campus or students had to travel to attend the lecture at Rusden. Although the Rusden and Burwood campuses are only eight kilometres apart, previous experience had indicated that students were loathe to travel between campuses because of the costs and loss of time incurred, as well as the inconvenience and the difficulty of parking. Similarly, it would have been inconvenient and time-consuming for the lecturer to present the same lecture twice because of the lecture demonstration format which was used in virtually every lecture. It was felt that the use of appropriate technologies could provide a solution to this problem.

## Using Optus

Demonstrations of chemical phenomena form a very important part of the lecture content which also involves exposition by the lecturer and the use of *Powerpoint* software[1] to display computer generated images. The computer display is closely linked to the chemical phenomena being demonstrated on the lecture bench. The consequent need for high quality visual images made the use of the existing video conference facilities impracticable. Moreover the videoconference suites lacked the facilities necessary for the presentation of chemical demonstrations and were too small for the number of students enrolled on each campus.

Because it was clear that the university's internal network lacked sufficient bandwidth for high quality cross-campus videoteaching, the assistance of the Optus Education channel was enlisted to deliver lectures, in real time, from the Rusden to the Burwood campus. The Education Channel is based on the Rusden campus, from which it delivers a variety of material to the main transmission site for distribution throughout suburban Melbourne over the company's optic fibre network.

In order to take advantage of the opportunity that this provided, the University authorities had to be persuaded to provide the necessary hardware in the theatre from which the lectures would be delivered together with a high grade link to the Optus control room. A schematic diagram of the hardware used on the Rusden campus is given as figure 1.

It was also necessary to prevail upon Optus to connect the Burwood campus to their network. This was not difficult as the company has a policy of connecting schools free of charge, however, because the theatre to which the lectures had to be delivered is so far from the university perimeter, it was also necessary to arrange for the University to run an optic fibre optic cable across the campus. In the event, it was the end of the second week of the semester before transmissions commenced. Fortunately a contingency plan had been put in place for delivery of the first few lectures. These were videotaped at Rusden and played at Burwood the following day. The practice of recording lectures was continued for the remainder of the semester and the tapes were made available in the libraries on both campuses. In addition to this, some students who had access to the Optus Education channel at home found it more convenient to watch the lectures there or to record them for subsequent viewing.

The relatively small number of students enrolled (98 distributed more or less equally across the two campuses) made it fairly easy to monitor their patterns of attendance. These are detailed in table 1.

| | Rusden students* | Burwood students* |
|---|---|---|
| View live at Rusden | 100 % | 6 % |
| View broadcast at Burwood | 0 % | 89 % |
| View and/or tape broadcast at home | ? | 3 % |
| View tape in library | 27 % | 12 % |

Table 1. Attendance patterns for *Foundations of Chemistry* Lectures.

* Students were asked to designate themselves as being based on either the Rusden or the Burwood campus. The totals in each column add to more than 100 % because some students gained access to lectures in more than one way.

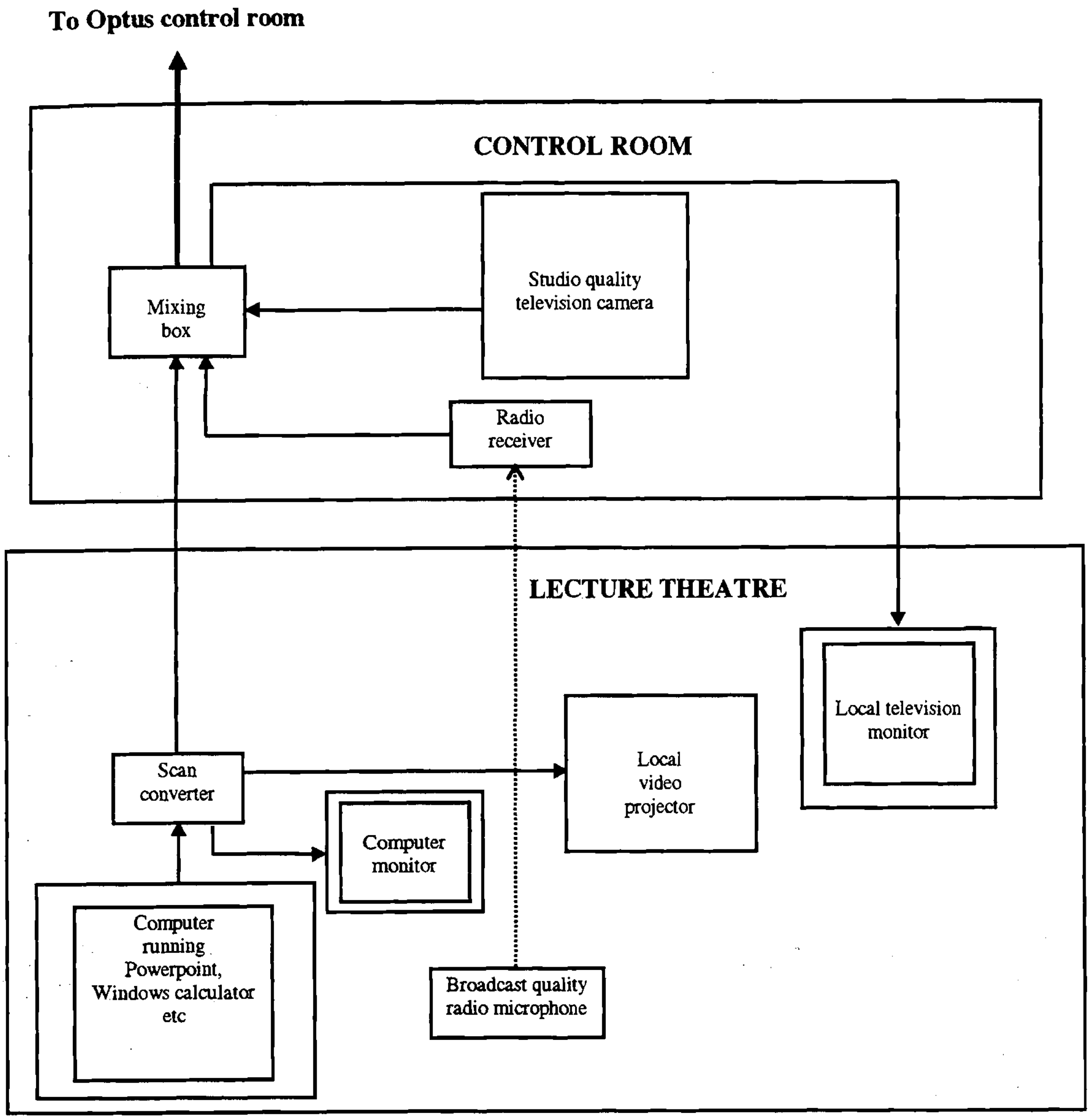



Figure 1. Schematic Diagram of Video Transmission Arrangements

**Laboratory work and tutorials**
In addition to three lectures each week, the unit involves tutorials and laboratory work. The author ran all of the tutorials on both campuses in order to ensure that all students had the opportunity to interact with me personally. Although this involved considerable effort, it was based upon the premise that students would be more likely to accept the technology if they saw the lecturer as someone who knew them and had a real concern for their welfare. Subsequent evaluation of the unit based upon verbal and written feedback from students on both campuses appears to validate this belief. There is no doubt that this approach compensated for the fact that the use of an external carrier made full two-way interactivity during lectures impossible.

Fortunately, access was made available to a laboratory on the Burwood campus, so laboratory classes were also conducted both there and at Rusden. Practical exercises were scheduled on the two campuses in alternate weeks with the same demonstrator running classes on both campuses. Consequently it was not necessary for any student to commute between campuses though some elected to do so. Those students who watched the lectures at home attended laboratory sessions on whichever campus was the more convenient.

## Supporting materials

A comprehensive printed summary of the lectures[2] was made available to all students who were thus relieved of the necessity taking their own notes during lectures. This left them free to concentrate upon the content, a situation which almost all of them appreciated. Students were also provided with copies of the examination papers that had been set over the previous three years together with detailed worked solutions. The lecture summary contained a series of graded problem sheets for which worked solutions were also available separately. The reason for not including them with the problems themselves was to discourage students from working the problems with the solutions in front of them.

## Outcomes

In 1997, *Foundations of Chemistry* was taught in this way more or less out of necessity. It did however, provide an opportunity to assess the advantages and disadvantages of videoteaching and to monitor and student acceptance of it as an alternative to face-to-face lectures. Because the two campuses were so close together and the student numbers relatively small, it was always possible for staff to commute between campuses and to interact personally with students individually or in small groups. Any shortcomings imposed by lack of face-to-face contact during lectures could be compensated for in other ways. These included having the lecturer run all of the tutorials and having the person who ran the laboratory classes sit in on many of the lectures on the Burwood campus. In addition, the use of a studio quality camera in filming the lectures enabled all students on both campuses to get a much closer view of many of the phenomena being demonstrated on the lecture bench than would have been safely possible in any other way. The fact that the subject matter of the unit was relatively simple permitted the lecturer to attend to the demands of the technology to an extent that would probably not have been possible in a more advanced unit so that it was always possible to lecture with one eye on the camera or the monitor.

At the conclusion of the unit, students were surveyed as to their views on this mode of delivery. Interestingly, a large majority of those who had only attended live lectures at Rusden expressed the opinion that receiving lectures on television from a remote site would be a vastly inferior way of learning. On the other hand the Burwood based students and those who attended lectures on both campuses overwhelmingly approved of the system that was used, with 42 % actually expressing a preference for the video link over live lectures and a further 30 % responding that they were equally happy with either a live lecture or the video link.

One consequence of this experiment was that those Burwood students who had experienced the delivery of *Foundations of Chemistry* by video link in first semester expected that the second semester chemistry unit would be delivered in the same way. Another was that Burwood based students who had been compelled to travel to Rusden for *Chemistry A*, the standard first semester unit which assumes a knowledge of secondary school chemistry, also began to demand access to video lectures on their home campus. Several students reported having persuaded their parents to subscribe to the Optus cable television service in order to gain access to the lectures at home thereby avoiding the necessity to attend on either campus. There was also some evidence that the lectures were watched by members of the general public inasmuch as the University started to receive enquiries from outsiders about their content and about other areas of chemistry.

As a result of student pressure, the highly complimentary responses from the Burwood students in relation to the delivery of this one unit, and our own desire to extend the experiment, it was decided to broadcast the second semester unit on the same basis. This unit, *Chemistry B*, takes students from both *Chemistry A* and *Foundations of Chemistry* and consequently attracts much larger numbers, typically around 250. Unfortunately it was not possible to run the laboratory classes on the Burwood campus for lack of a suitable laboratory, nevertheless all of the students saw not having to travel to Rusden for lectures or tutorials as a very big advantage.

This year the experiment has been extended even further with both *Chemistry A* and *Foundations of Chemistry* being delivered over Optus in first semester and *Chemistry B* planned for second semester. In addition, two second year Biochemistry units are being delivered in the same way. Increasing numbers of students are reporting watching the lectures at home and a significant number of part time students are watching the lectures in the Rusden and Burwood campus libraries on Sunday afternoons.

As a result of last year's success, the University administration has recently embraced this technology and upgraded the intercampus microwave links. It is currently in the process of installing equipment for videoteaching on four of its six campuses. This will enable lectures to be transmitted between campuses without reliance upon an outside party. As a result, it is unlikely that students in 1999 will be able to get out of bed, walk into their living rooms and learn about atomic structure while eating their breakfast, or that viewers in suburban Sydney will be entertained by exploding hydrogen balloons or colourful transition metal complexes.

References

1. *Powerpoint* ® is part of Office 97, published by Microsoft Corporation, Redmond, 1996.
2. Clift, D.A., *Foundations of Chemistry Lecture Summary*, Deakin University, Clayton, 1998

# WALKING AND TALKING ON AND UNDER WATER

**David Druskovich**[a] **and David Ryan**[b]

[a]*Central Queensland University, Rockhampton, Queensland, 4702*
[b]*AUSTA Energy, Murarrie, Brisbane, Queensland, 4172*

**Abstract**

A collaborative project involving Central Queensland University, the electricity support organization AUSTA Energy, and four Queensland power stations is described. The process that was used in setting up and coordinating the project is analyzed and discussed.

This paper describes the development of *Guidelines for the Total Management of Treated Water Systems in Queensland Power Stations* by the team. The objective of the project was to minimize corrosion in the stations' Treated Water (TW) circuits by assessing the corrosion inhibitor technologies being used. The challenge faced by the group was not only to choose an inhibitor that was "chemically effective" but, above all, to ensure that it was Workplace Health and Safety, and also environmentally acceptable.

The strategy used to obtain and collate the materials needed to write the guidelines is discussed and the outcomes of the project are presented.

## Introduction

Johnson and Donaghue (1996) have commented on the very low percentage of Australian university academics who chose to take a study leave program at a large chemical industry. This influenced one of the authors to spend an Outside Study Program (OSPRO) in the Queensland electricity generation industry during 1997. This was an interesting experience, not only because of the challenges arising from the project, but also in part to the major restructuring changes that the industry was undergoing at the time.

The objective of the OSPRO was to review the chemical inhibitors used to minimise metallic corrosion in the TW circuits in Queensland fossil fuel-fired power stations and to make a recommendation on the ideal inhibitor. It needed to be not only chemically effective but also Workplace, Health and Safety compliant, and environmentally friendly.

Prior to the restructure that commenced on July 1, 1997, AUSTA Electric was a single body running the States power generation facilities. Cooperation between the stations was commonplace where a Chemists Group routinely addressed major chemical problems facing the industry and devised strategies for their successful solution. Most of the research and development work was done by the Engineering and Technology support group and all their intellectual property was distributed within the industry. When the OSPRO commenced in July 1997, the industry structure changed dramatically. Four independent organizations were established by the State Government, three generating bodies and an electricity support organization, AUSTA Energy. The objectives of the OSPRO had to be fine-tuned to fit in with the new structure. The problem being investigated was still common to all the power generation facilities. However, the situation was now one where the facilities were all "independent" and were competing with one another.

**Results and Discussion**

The structure of the team that was set up to investigate the problem is shown in Figure 1.

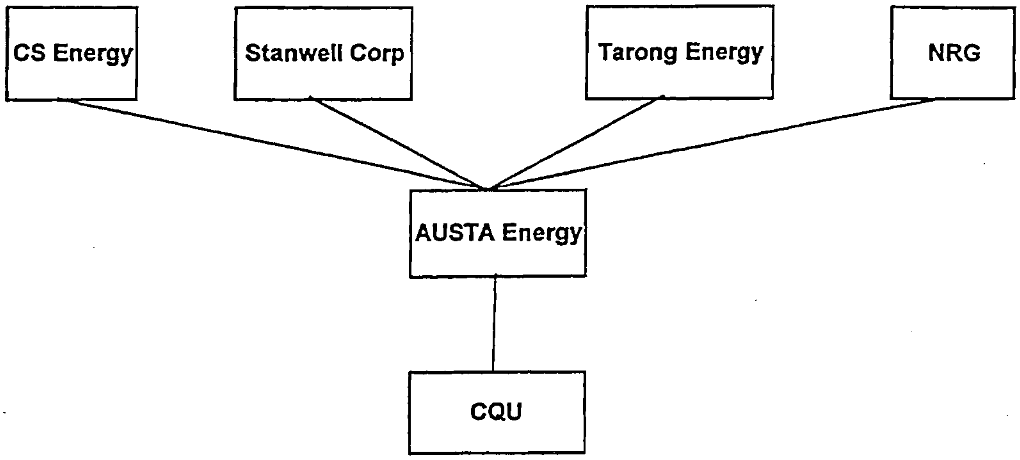



**Figure 1** **The structure of the team investigating the Treated Water review for Queensland power stations**

AUSTA Energy coordinated the project. since they had both an excellent overview and had fully documented TW practices used by all stations since commissioning (Chalmers, 1993; Flitt, 1994; Kelly, 1990; Knights, 1993; and Robinson, 1995). The objective was to critically evaluate the existing literature and to design a *best practice* to be adopted by all stations.

TW is a cooling system for a range of boiler and plant turbine equipment including primary coolers for Unit Cycle sampling. Heat is rejected from the TW system via the circulating water system (Queensland Electricity Commission, 1993).

The choice of materials for TW Systems is governed by the need to

- maximise heat transfer in the cooling system
- reduce scale formation and microbiological growth
- minimise corrosion

With power station owners demanding that plant equipment should have better than a 25 to 40 year lifetime, it is imperative for scientists and engineers to ensure that stations have a *best practice* procedure to achieve this goal. Unfortunately, metals and alloys most suitable for maximising heat transfer in the system are not always the best materials choice from a corrosion management point of view, and vice versa. Therein lay the challenge!

The task was to decide on the most suitable corrosion inhibitor for the aqueous phase in the TW circuits. Even though it was known that corrosion inhibition should begin at the design and materials selection stage, current materials at the stations had to be used. In addition, the choice of inhibitor had to be Workplace, Health and Safety compliant, and environmentally friendly.

The initial step was to review the extensive literature held by AUSTA Energy. TW Chemistry had been documented since the 1970s. Each station had developed its own inhibitor treatment strategy for TW circuits, and they all used a different approach! The reasons for this were mainly historical. The choice of inhibitor treatments often reflected attempts to overcome costly TW shutdowns caused by tube corrosion failures.

The next phase was to interview station chemists and technical staff involved with TW operation and maintenance. This was done by visits to the power stations, interviews and an extensive questionnaire designed to evaluate their strategy to TW management.

Prior to writing the *Guidelines for the Total Management of Treated Water Systems in Queensland Power Stations,* the authors spent a reasonable amount of time on instructional design. It was realized that feedback from Station personnel on all aspects was critical, as the document being developed was one that the station people would be working with, and relying on, to solve problems that might occur in the system.

A major hurdle was to convince station chemists of the need to reassess the use of very effective TW inhibitors such as hydrazine and zinc chromate. The argument employed was that it was essential to use chemicals having a minimal impact on personnel and on the environment.

The next obstacle, was to convince stations personnel that they could change inhibitors without significant damage to the TW systems. The very significant research and development by the industry over the last 30 years, showed that the change could be successfully implemented (Flitt, 1994).

The *best practice* advocated was:

- a low-level phosphate inhibitor
- the use of demineralised water
- pH maintained at 9.0 to 9.5

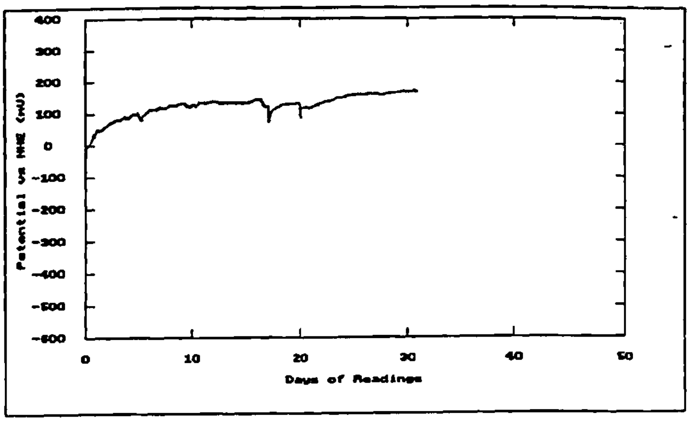
A recommended procedure for TW management with the above corrosion inhibitor was written for technical personnel maintaining the circuits (Druskovich, 1998). Issues such as TW pre-treatment, system control ranges, monitoring, and system blowdown and chemical dosing were addressed.

The final aspect considered in the *Guidelines* was the issue of a corrosion management strategy for TW Systems. This is a topic which, although important, has in the past been neglected because of more pressing priorities, and because it is often seen as a highly technical task best left to experts. This view has changed in the last few years since reliable, user-friendly instrumentation, available at a reasonable cost, can be used to monitor this important parameter.

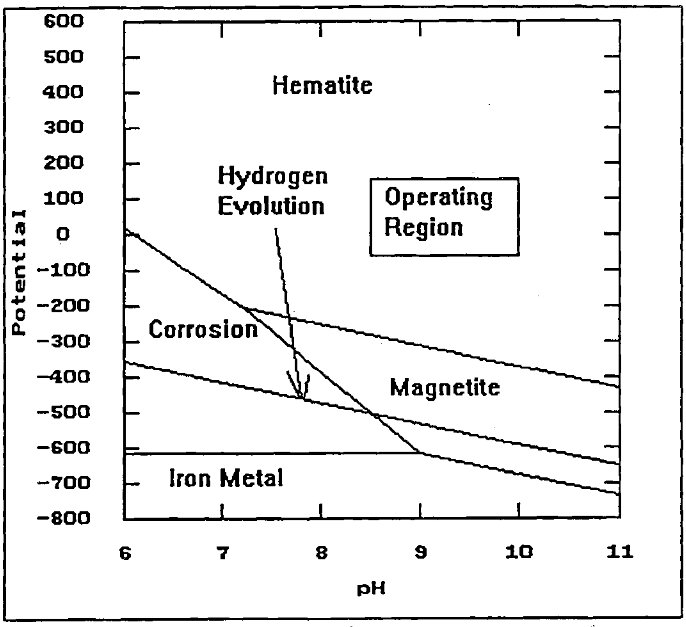
Corrosion tests recommended as essential were:

- potential monitoring
- coupon analysis
- linear polarisation resistance (LPR)

The usefulness of the potential monitoring technique is illustrated in Figure 2 which shows potential/time data actually obtained at a Queensland power station. When the potential data is superimposed on an E/pH, or Pourbaix diagram, it may be seen that the system is in a "safe" operating region. Such a monitoring system could easily be automated and the result displayed on a computer screen. If the TW system failed for any reason, and the potential moved to an "unsafe" region, an alarm could be triggered to alert the operator to attend to the system.




(a)




(b)

**Figure 2** **(a) Corrosion potential-time data for a Queensland power station (b) The data displayed on a Pourbaix diagram; illustrating that the system is in a "safe" operating mode.**

## Conclusion

This paper has presented the strategy that was developed to review the TW practices in Queensland power stations. Guidelines have been written which advocate the use of a workplace and environmentally compliant corrosion inhibitor, designed to extend the life of TW metal components and reduce costly maintenance.

## Acknowledgements

The authors would like to thank CS Energy Ltd, Stanwell Corp Ltd, Tarong Energy Corp Ltd and NRG (Gladstone) for permission to publish this paper. One of us (DD) wishes to thank Central Queensland University and AUSTA Energy for their financial support and encouragement during the OSPRO.

**References**

Chalmers, D. (1993) *Summary of Initial Test Results for Treated Water Systems, Stanwell Power Station*, CTM 93/093 (I).

Druskovich, D. (1998) *Guidelines for the Total Management of Treated Water Systems in Queensland Power Stations,* AUSTA Energy Report No. 98/0028.

Flitt, H. (1994) *Replacement of Treated Water Cooling System Inhibitor – Swanbank Power Station* CTM 94/062 (F).

Johnson, G. and Donaghue, P. (1996) Strategic Industry Link Recommendation, Professors and Heads of Chemistry Meeting, Canberra.

Kelly, G.J., (1990) *Stanwell Power Station : Review of Proposed Treatment Practice for Auxiliary Cooling Water Systems.*

Knights, D. (1993) *Advisable Characteristics of a Treated Water Corrosion Inhibitor Treatment,* File 385/40/2.

Queensland Electricity Commission (1993) *Chemical Control and Monitoring of Treated Water Systems,* GBU-CP-05.

Robinson, R. (1985) *History of Treated Water Systems, Tarong Power Station,* PF 551/08/9.

# IMPROVING STUDENTS' UNDERSTANDING OF HIGH SCHOOL CHEMISTRY CONCEPTS

**Patrick Garnett**

*Edith Cowan University, Joondalup, Western Australia 6027*

## Abstract

Research at the secondary and tertiary levels indicates that students' conceptions of chemical phenomena are often inconsistent with the scientific conceptions they are expected to learn; are resistant to change; and can be a significant factor in students' subsequent learning. Underpinning students' understandings of these topics is their inability to visualise the particulate/submicroscopic nature of matter in its various states and the processes underlying physical and chemical change. In addition, a range of curriculum and pedagogical practices have been identified which appear to influence the development of students' alternative conceptions.

Studies that document students' understandings of chemical phenomena have implications for teaching and learning. From the research reviewed, the following factors have been identified that influence student conceptions: preconceptions, personal experiences and inadequate prerequisite knowledge; use of everyday language in a scientific context; oversimplification of concepts and use of unqualified, generalised statements; use of multiple definitions and models; rote application of concepts and algorithms; and inability to visualise the particulate submicroscopic nature of matter. Various strategies for reducing students' alternative conceptions and improving students' understanding of chemistry concepts are proposed consistent with a social constructivist framework.

## Introduction

Science education research prior to the 1960s reflected the pre-eminent position held by behavioural psychology in the first half of the twentieth century. An agricultural research paradigm prevailed with a focus on the effects of various treatments on student performance. The actual process of learning within human consciousness was largely ignored because it could not be directly observed.

The change in focus towards a consideration of the actual process of learning and the learner's construction of knowledge was largely due to the influential work of Jean Piaget. Piaget was an epistemologist, interested in the development of knowledge in humans. Piaget's approach was a radical change to the way that researchers viewed learners' construction of knowledge. Piaget proposed that knowledge is constructed as the learner seeks to organise their experiences in terms of pre-existing cognitive structures or schemes (Bodner, 1986). Equilibration, the process of adaptation, involves two complementary processes, assimilation and accommodation, and is an internal self-regulatory mechanism by which the learner makes sense of their environment. In assimilation, learners interpret experiences within existing cognitive structures or schemas; the new experiences are incorporated within existing structures. In accommodation, the learner's experiences do not "fit" existing cognitive structures which must be restructured to resolve this discrepancy. According to Piaget humans pass through a set of distinct developmental stages - sensorimotor, preoperational, concrete operational and formal operational from birth to adulthood. The consistent and global nature of developmental stages is one aspect of Piaget's Theory that is now less strongly advocated; it appears that knowledge develops in learners unevenly, both temporally and across different discipline domains. Learners' reasoning depends not only on the general level of development but also on the familiarity and difficulty of the context and task, and the level of language involved. Nevertheless, the twin concepts of assimilation and accommodation remain important within the context of modern views on learning.

Foremost among those in science education who challenged the utility of the Piagetian approach were Novak and coworkers (eg. Novak, 1978) who argued in favour of Ausubel's Theory of Meaningful Learning. This theory emphasised that learning involved the development of a framework of specific concepts as the learner sought to make sense of experience. Ausubel distinguished between meaningful and rote learning, with meaningful learning occurring only when learners relate new knowledge to concepts and propositions that they already know. This proposition led to Ausubel's famous statement that "the most important single factor influencing learning is what the learner already knows" (Ausubel, 1968).

## Alternative conceptions research

The science education literature of the 1980s and 1990s contains numerous studies of students' understandings of scientific concepts and phenomena. These studies indicate that students' conceptions are often inconsistent with the scientific conceptions they are expected to learn. Various terms have been used to describe these alternative views, including alternative frameworks, alternative conceptions and misconceptions. For the purposes of this paper the term 'alternative conceptions' will mean a conception that differs from that agreed by the scientific community (Gilbert, 1983).

Research on alternative conceptions has established (Garnett, Garnett and Hackling, 1995; Gabel and Bunce, 1994; Wandersee, Mintzes and Novak, 1994; Nakhleh, 1992) that:

- there is a diversity in students' knowledge about scientific concepts and phenomena
- students' conceptions are often inconsistent with those held by the scientific community
- students' conceptions are often resistant to change, especially where the scientific conceptions are counter intuitive
- students' conceptions can influence subsequent learning
- students' ideas within specific content domains tend to follow 'conceptual trajectories' that are common across different educational systems and cultures
- students can hold inconsistent conceptions that they apply in different contexts
- students' alternative conceptions have numerous origins including diverse personal experiences, language, culture, teaching and curriculum materials

Alternative conceptions research has led to an acceptance that students' current knowledge plays a critical role in any intellectual activity. Learning is no longer viewed as the passive accumulation of information but as a process of conceptual change as learners use existing knowledge to make sense of new information. In response to this awareness of students alternative conceptions, increasing attention has been focused on the notion of conceptual change. The seminal paper by Posner, Strike, Hewson and Gertzog (1982) proposed that the replacement or reorganisation of naive conceptions requires learner dissatisfaction with existing conceptions and that the new conceptions be intelligible (understandable), plausible (believable) and fruitful (worthwhile). In an extension of this view Hewson (1981) suggests that it is useful to consider two forms of conceptual change:

- capturing new conceptions (conceptual capture; assimilation); where new learning is consistent with current views

- exchanging existing conceptions for new conceptions (conceptual exchange; accommodation)

In this approach, learning can therefore be considered (Duit and Treagust, 1998) as occurring via continuous pathways (assimilation) and discontinuous pathways (accommodation). In the former, students learn new knowledge by making connections to what they already know; the new conceptions are consistent with and are added to existing conceptual frameworks. In the latter, there is a change in the students' existing conceptual frameworks to accommodate new information that is inconsistent with existing frameworks. According to Hewson (1996) a key concept in accommodation is the relative status of existing and new concepts for the learner. Conceptual change is dependent on a change in the relative status of the conceptions, with some concepts increasing in status and others decreasing in status. Thus an important feature of teaching and learning is changing students' naive conceptions to more scientific conceptions by showing that scientific conceptions are more fruitful.

A considerable number of research studies in the area of conceptual change have focused on the use of conceptual or cognitive conflict strategies aimed at demonstrating to students that current naive conceptions are inadequate and thereby increasing the likelihood of exchanging these conceptions for more scientific conceptions. The effectiveness of these conceptual change strategies has been subject to considerable debate. Some researchers are sceptical of the efficacy of conceptual change strategies and believe that extinction is difficult or improbable (Solomon, 1994) while others are more optimistic (Wandersee, Mintzes and Novak, 1994). Although there is continuing debate on the issue it does seem that conceptual change is rarely a sharp exchange of one theory-like set of meanings for another. Conceptual change is more often a gradual process involving conceptual addition in which cognitive restructuring occurs but without necessarily extinguishing prior conceptions. This approach recognises the existence within learners of parallel or plural conceptual schemes concerning aspects of science in different contexts. While learning does involve the restructuring of ideas it does not necessarily result in the extinction or abandonment of prior conceptions. Conceptual change strategies based on the extinction of naive conceptions and their replacement by scientific conceptions seems to be particularly unlikely where the concepts involved are counter intuitive.

## Constructivism

Alternative conceptions research is largely interpreted within the constructivist learning paradigm. Social constructivist learning theory (Duit and Treagust, 1998; Treagust, Duit and Fraser, 1996; von Glasersfeld, 1993; Tobin and Tippins, 1993) includes the following important elements:

- Students actively construct new meaning by using their present conceptual frameworks to make sense of their experiences of the physical world or the words and images they see or hear. Learning is the active construction of knowledge by the learner, and should not be viewed as the transfer of knowledge. Knowledge is actively developed by the cognising subject and what the learner already knows is of considerable importance.
- Cognition is functional and adaptive; learners construct "viable" knowledge, ie. knowledge that is useful, rather than necessarily representing "reality". Knowledge about reality is a human construction and it is only possible to know about reality in a personal and subjective way.
- Knowledge is personally constructed but is also socially mediated. The process of constructing meaning is embedded in a social setting of which the individual is a part.

Learners construct knowledge to make sense of their environment; this requires the construction of viable and useful knowledge. This approach considers that knowledge is constructed by each individual through active engagement with the physical and/or social environment. Knowledge construction by the learner requires an active process of interpretation within this social and cultural setting. The construction of knowledge is viewed as a search for a viable "fit" rather than a match with "reality". Knowledge is viable if it works.

The earlier "personal" forms of constructivism emphasised the individual construction of knowledge; knowledge was also viewed as stored mental models of the outside world. Emphasis was placed on the learner's personal construction of knowledge and the conceptions developed about natural phenomena. This approach emphasised the interaction of learner's cognitive structures with physical events and phenomena.

The newer forms of "social" constructivism place greater emphasis on the social milieu in which learning takes place. Learning is viewed as more than knowledge construction based on interaction with physical reality. Knowledge is both individual and social. It is a set of socially negotiated understandings of events and phenomena that comprise the experienced universe. Knowledge is, therefore, personally constructed but it is also socially mediated, in two ways; firstly, through the mechanism in which it is developed and acquired, and secondly, because our ways of knowing, intellectual processes and language itself are socially derived. This approach recognises science as symbolic and socially constructed and communicated. Science is viewed as the constructs used to interpret nature rather than the physical events and phenomena themselves.

## Examples of alternative conceptions in high school chemistry

There is now an extensive literature on alternative conceptions held by chemistry students at high school and the secondary/tertiary interface. Space precludes an exhaustive description of these studies but several reviews are available and the table below identifies a selected sample of alternative conceptions from these sources (Garnett, Garnett and Hackling, 1995; Gabel and Bunce, 1994; Griffiths, 1994; Nakhleh, 1992).

Table 1: High school students' alternative conceptions in chemistry

**1. Particulate nature of matter**

*Nature and characteristics of particles*

1.1 Individual atoms and molecules have macroscopic properties eg freeze, expand, malleability, colour
1.2 Atoms and molecules are alive
1.3 Compounds (eg water) consist of mixtures of their constituent elements (eg hydrogen and oxygen)

*Arrangement and spacing of particles*

1.4 Matter is continuous
1.5 Matter (eg air and water) fills the spaces between particles in other substances

*Properties of atoms and molecules in different phases*

1.6 Atoms and molecules have different properties in different phases (eg mass, size, shape)
1.7 Heat/temperature affects the properties of atoms and molecules in a particular phase (eg size, shape)

*Phase changes*

1.8 When solids melt water runs out
1.9 When liquids boil air escapes
1.10 When water boils hydrogen and oxygen are released

**2. Balancing and interpreting chemical equations**

2.1 Formula subscripts are not associated with atomic groupings
2.2 Chemical equations are not associated with a particulate representation
2.3 Chemical equations are not associated with the representation of a dynamic process
2.4 Equation coefficients are not associated with the relative numbers of reactant and product species

**3. Chemical equilibrium**

*Characteristics of chemical equilibrium*

3.1 There is a simple arithmetic relationship between the concentrations of reactants and products (eg "equal" or related according to stoichiometric coefficients)
3.2 Equilibrium is not a dynamic process
3.3 Equilibrium involves "oscillating" behaviour

*Reaction rates*

3.4 Forward reaction rate increases as the reaction "gets going"
3.5 Forward reaction completed before reverse reaction commences
3.6 A catalyst can affect the rates of forward and reverse reactions differently

*Constancy of equilibrium constant*

3.7 K changes when equilibrium is restored following disturbance (at constant temperature)
3.8 K is independent of temperature

*Inappropriate use of Le Chatelier's Principle and interrelatedness of concentrations of reactants and products*

3.9 Changes to an equilibrium system increase the rate of the favoured reaction and decrease the rate of the non-favoured reaction
3.10 A reaction can proceed to alter the concentration of a reactant or product without necessarily affecting the concentrations of other reactants and products

Table 1: High school students' alternative conceptions in chemistry (cont)

**4. Acids and bases**

*Acid-base strength*

4.1 Strong acids have a higher pH than weak acids
4.2 Strong acids contain more hydrogen atoms than weak acids
4.3 More hydrogen gas is displaced from a strong acid than a weak acid

*Presence of hydrogen and hydroxide ions in all aqueous solutions*

4.4 Acid solutions contain no hydroxide ions
4.5 Base solutions contain no hydrogen ions
4.6 Salt solutions contain neither hydrogen ions nor hydroxide ions

*Bronsted-Lowry theory*

4.7 Neutralisation always results in the formation of neutral solution
4.8 Conjugate acid-base pairs consist of positive ions and negative ions
4.9 Conjugate acid-base pairs consist of the species involved in the proton transfer or the non-conjugate acid-base pair

**5. Oxidation-reduction and electrochemistry**

*Electric circuits*

5.1 Electric current is the flow of positive charge (electricity is different in physics and chemistry)
5.2 Electric current in electrolytes is the flow of electrons
5.3 Electrons move through solution by
- being attracted alternately from one ion to another
- being "carried" by an ion

*Oxidation and reduction*

5.4 Oxidation states can be assigned to polyatomic ions and is based on the charge of the ion
5.5 In all chemical equations the "addition" and "removal" of oxygen and hydrogen can be used to identify oxidation and reduction
5.6 Oxidation and reduction processes can occur independently

*Electrochemical cells*

5.7 The anode is positively charged because it loses electrons; the cathode is negatively charged because it gains electrons
5.8 Negatively charged anode attracts cations; positively charged cathode attracts anions
5.9 The salt bridge supplies electrons to complete the circuit
5.10 Half cells need not be electrically neutral

*Electrolytic cells*

5.11 No reactions occur at inert electrodes
5.12 There is no relationship between the predicted emf and the magnitude of the applied voltage required to bring about electrolysis
5.13 Processes in electrolytic and electrochemical cells are reversed (eg in electrolytic cells oxidation occurs at the cathode compared with electrochemical cells where oxidation occurs at the anode; anions and cations migrate towards different electrodes in different cells)

## Possible sources of alternative conceptions

Clearly there are many potential sources of students' alternative conceptions in chemistry. While some conceptions undoubtedly are idiosyncratic to particular students, the consistency of alternative conceptions across educational systems and cultures suggests that a consideration of potential sources of their origins may be worthwhile. Outlined below is a brief description of some possible sources of students' alternative conceptions.

### Preconceptions, personal experiences and inadequate prerequisite knowledge

Students have their own unique private world experiences they bring to instruction. This includes their interactions with the physical world together with the social and cultural experiences that make up their everyday lives. As a result students will have established conceptions in many cases quite different from those accepted by the scientific community. In physics, alternative conceptions such as "heavier objects fall faster" and "objects moving at constant velocity are experiencing a constant force" are well known. In chemistry, conceptions such as "objects/substances get lighter when burned" and "reaction rates increase as the reaction gets going" have obvious origins from personal experience.

### Use of everyday language in a scientific context

The context-specific meanings of language are well known and represent a potentially significant source of students' alternative conceptions. "Everyday" language and "scientific" language often have quite different meanings with the latter often being associated with a much greater level of precision. Terms such as weight, particle and equilibrium, can have different meanings in everyday and scientific contexts. In addition, terms such as "ionisation" can have different meanings even within the discipline of chemistry itself.

The use of normal, everyday language, either within textbooks or classroom discourse, can have quite unintended consequences. For example, "water is made up of hydrogen and oxygen" can mean different things depending on the listener's own cognitive framework; to an establshed chemist the statement is quite reasonable and understood to imply "chemically combined" whereas to naive learners the image created may be that of a mixture of unaltered elemental hydrogen and oxygen. Similarly the statement "the ions carry the charge" was interpreted by some students (Garnett and Treagust, 1992b) as a mechanism by which the ions actually "piggy back" electrons through solution.

### Oversimplification of concepts and use of unqualified, generalised statements

Alternative conceptions can develop when educators, in attempting to simplify concepts, provide descriptions that may be limited or misleading (Bodner, 1986). For example, statements such as "the principles of operation of electrochemical and electrolytic cells are reversed" can lead to inappropriate conceptions if students interpret them literally and apply them more extensively than intended (Garnett and Treagust, 1992b).

### Use of multiple definitions and models

The use of multiple definitions and models has been identified as a source of confusion in studies of students' alternative conceptions in acid-base behaviour (Carr, 1984) and oxidation-reduction behaviour (Garnett and Treagust, 1992a). While the use of different models of increasing sophistication is probably justified in illustrating the tentative and developmental nature of science, there is a need to use these models carefully and clearly enunciate their limitations. In addition, different subjects such as chemistry and physics sometimes use conventions and terminology differently when dealing with the same concept. The use of conventional flow current and electron flow current certainly caused considerable learning difficulties for some very able students in a Western Australian study (Garnett and Treagust, 1992a).

### Rote application of concepts and algorithms

Research has identified a tendency for students to reduce theoretical knowledge and principles to a 'factual' level and to 'apply' this in a rote fashion (Baird, 1986). This tendency has also been found in studies of students' applications of Le Chatelier's Principle (Hackling and Garnett, 1985) and in approaches used in balancing redox equations (Garnett, Garnett and Treagust, 1990). The clear implication here is to present material in a way that encourages students' understanding rather than in ways that promote rote learning and the unthinking application of algorithms.

### Inability to visualise the particulate submicroscopic nature of matter

Many of the alternative conceptions in chemistry can be attributed to students' inability to visualise the particulate/submicroscopic nature of matter. The theoretical basis of chemistry is very much associated with models of atomic/molecular behaviour which are, quite obviously, inaccessible to students (and scientists) in any directly observable way. The work of Johnstone (1991), suggesting that chemists work at three levels - the macroscopic (or observable, real world), submicroscopic/particulate (unobservable models and theories of atomic/molecular behaviour) and symbolic (chemical equations and mathematical representations) is now widely recognised. Chemists and chemistry teachers operate quite comfortably within and across these different modes of thinking. For students however, working in these three alternative modes poses significant difficulties. In particular, students seem to have difficulty in visualising the particulate/submicroscopic level which is beyond their experience and only accessible through the use of diagrams, models, analogies or computer simulations. Furthermore, illustrations in curriculum materials of the particulate/submicroscopic nature of matter and chemical processes can lead to further misunderstandings where these illustrations are inadequate (Hill, 1988).

### Endowing objects with human/animal characteristics

Several studies have identified students' tendencies to endow objects with human/animal characteristics. While this is particularly prevalent among younger students, it is also evident in more mature populations. Statements such as "electric current chooses the path of least resistance" and "atoms try to obtain a share in eight electrons" may be a contributing factor. This again suggests the need for more precise use of language.

## Implications for the curriculum and teaching and learning

### General comments from a social constructivist perspective

Constructivist learning theory proposes that students actively construct new meaning by using their present conceptual frameworks in ways that make sense to them. Knowledge is personally constructed through the learner actively engaging with the physical and/or social environment (Roth, 1993) but is also socially mediated. The process of constructing meaning is embedded in a social setting of which the individual is a part.

Constructivist learning theory does not imply a unique preferred instructional approach. It is, however, as described by Tobin and Tippins (1993), a useful theoretical referent with which to assess the appropriateness of various learning environments in terms of their potential to maximise student learning. Constructivism challenges the so-called transmission approaches to teaching and absorption views of learning. The notion of the learner's mind as a 'tabula rasa' to which scientific conceptions are simply transmitted cannot be sustained. Within this context it is important to consider the curriculum, learning experiences and learners together rather than as separate entities.

Learning is a complex interplay of personal experience, language and socialisation and the teacher has an important role to play in facilitating the social discourse associated with science learning. This includes introducing the phenomena and symbolism of science, helping students to establish links and bridges between their current conceptions and those associated with more scientific conceptions.

Research indicates that exemplary chemistry teachers may employ quite different approaches to their teaching (Garnett and Tobin, 1989). However, it is reasonable to start from a position that teachers should plan learning experiences that develop students' conceptions towards those accepted by the science community. This involves identifying and being sensitive to students' prior conceptions, encouraging students to take greater responsibility for their own learning, and providing learning experiences that progress student understanding. This may include hands on activities, individual activities, and a range of social interactions such as peer group, teacher-group and teacher-class discussions. Teachers need to monitor student understanding, listen, diagnose, challenge, negotiate and guide in the quest of improved understanding and more appropriate scientific conceptions. Roth likens the teaching and learning process to enculturation and cognitive apprenticeship as the student moves to progressively develop their scientific knowledge. Terms such as cognitive apprenticeship, scaffolding, coaching and situated modelling relate to the facilitation of enhanced levels of understanding through the learner's interaction with their peers or teachers. The development of this enhanced level of understanding occurs in what Vygotsky (1986) describes as the zone of proximal development. Learning occurs as learners appropriate new knowledge or reconstruct their current knowledge.

## Specific strategies

As we search to bridge the gap between theory and practice it is worth considering several strategies that have been suggested to enhance student understanding and the development of appropriate scientific conceptions.

### Prior conceptions

An important aspect of constructivism, and one previously advocated by Ausubel (1968), is the importance of being aware of students' prior conceptions and designing instruction on that basis. An extension of this suggestion is that, as teachers, we all need to be more aware of the nature of commonly held student alternative conceptions. The establishment of students' prior conceptions, through careful questioning, discussion or written tasks, is an important first step both in planning subsequent instruction and in helping students to articulate and reflect on their current conceptions.

### Conceptual change strategies

Conceptual change strategies usually are based on approaches such as those proposed by Posner et al (1982) and Driver and Oldham (1986). Common elements in these approaches include encouraging students to articulate their own conceptions; students evaluating their understanding in situations that may create conceptual conflict (eg. demonstrations, application in new situations, student-student and student-teacher discussions); fostering the restructuring of students' conceptions; and applying these modified understandings in new situations. There is continuing debate regarding the efficacy of this approach and Wandersee et al (1994) have suggested that while success is less likely where the scientific conception is counter intuitive, several research studies have demonstrated success. It is unlikely, however, that conceptual change will be a sharp exchange involving the substitution of naive conceptions with scientifically valid conceptions. Conceptual restructuring is more likely to be incremental, with students moving more gradually towards scientific conceptions.

Teaching for understanding

As previously mentioned, students tend to reduce theoretical knowledge to a factual level and apply this in a rote fashion. As teachers, we need to emphasise to students the importance of seeking to fully understand the scientific conceptions they are taught. The content and experiences to which students are exposed should be selected with this objective in mind. In addition, when teaching some of the more complex topics in chemistry, the rote, unthinking application of algorithms to obtain answers should be avoided. Topics such as the application of Le Chatelier's Principle, the writing of balanced redox equations and the application of the factor label method of solving stoichiometry problems commonly are associated with such approaches.

Examples of active learning strategies likely to promote student engagement and understanding include the following:

- construction of explanatory tables
- elaborate/explain exercises (across Johnstone's levels of thinking)
- predict-observe-explain exercises (across Johnstone's levels of thinking)
- 'guess the rule' sessions
- drawing diagrammatic representations of complex procedures (eg volumetric analysis)
- drawing particulate representations of matter and chemical processes
- laboratory investigations

Use of language

Language creates different mental pictures for different people and is critical to the process of thinking and knowing. As well, our use of language in scientific contexts is a highly significant factor affecting students' understanding. Mention has been made previously of student confusion arising from the different meanings of words in everyday and scientific contexts. In addition, the use of particular phrases can be interpreted differently by students from the way intended by teachers and textbook writers. Clearly there is a need to use words and expressions that are unambiguous and accurately convey to students our intended meanings.

Metacognitive processes

Several writers (eg. Baird, 1986) have stressed the importance of inculcating in students the practices of self-reflection and metacognition, and encouraging students to become more responsible for their own learning. In addition to encouraging students to question (what am I learning about? what are the important ideas here? how does this relate to?...)

there are several strategies that can help students to explore their current conceptual knowledge and the relationships between these concepts. These include:

- concept mapping
- construction of flow diagrams
- construction of Venn diagrams
- creative writing exercises
- small group discussions
- feedback quizzes

Use of multiple definitions and models

The difficulties posed for students through using multiple definitions and models was described previously. While the use of multiple approaches may be desirable in some circumstances, it is important to be aware of the difficulties this may cause for students. Teachers should take care to clearly enunciate the reason for using different models, the strengths and weaknesses of these models and their particular limitations.

Improving students' abilities to visualise the particulate/submicroscopic nature of matter

Students' inability to visualise the particulate/submicroscopic nature of matter and the dynamic nature of chemical phenomena has been highlighted as a major area of difficulty for students as they seek to develop a sound conceptual understanding of chemistry. As Nakhleh has suggested: "There are profound misconceptions in the minds of many students from a wide range of cultures concerning the particulate and kinetic nature of matter." The difficulties students experience because of the abstract, unobservable particulate basis of chemistry suggests that students need to have more experience manipulating molecular models, be provided with and construct more diagrammatic representations of matter and work with appropriate computer simulations. Modern multimedia technology offers exciting possibilities in this regard.

## Conclusion

This paper has described a range of students' alternative conceptions held by high school chemistry students and the contribution of alternative conceptions research to our understanding of student learning. Teaching strategies that are based on an understanding of students' alternative conceptions and their possible origins, and a social constructivism approach have the potential to considerably enhance students' understanding of scientific conceptions commonly found in high school chemistry curricula.

## References

Ausubel, D.P. (1968). *Educational Psychology: A Cognitive View.* New York: Holt, Rinehart and Winston.

Baird, J. (1986). Language and teaching: The need for change. In J.R.Baird and I.J.Mitchell (Eds) *Improving the Quality of Teaching and Learning: An Australian Case Study - The Peel Project.* Melbourne: Monash University Printery.

Bodner, G.M. (1986). Constructivism: A theory of knowledge. *Journal of Chemical Education, 63,* 873-878.

Carr, M. (1984). Model confusion in chemistry. *Research in Science Education, 14,* 97-103.

Driver, R. and Oldham, V. (1986). A constructivist approach to curriculum development in science. *Studies in Science Education, 13,* 105-122.

Duit, R. and Treagust, D.F. (1998). Learning in science - from behaviourism towards social constructivism and beyond. In B.J.Fraser and K.G.Tobin (Eds) *International Handbook of Science Education.* London: Kluwer Academic Publishers, p. 3-25.
Gabel, D.L. and Bunce, D.M. (1994). Research on problem solving: Chemistry. In D.L. Gabel (Ed) *Handbook of Research on Science Teaching and Learning.* New York: Macmillan, p. 301-326.
Garnett, Pamela J., Garnett, Patrick J. and Treagust, D.F. (1990). Implications of research on students' understanding of electrochemistry for improving science curricula and classroom practice. *International Journal of Science Education, 12,* 147-156.
Garnett, Pamela J. and Treagust, D.F. (1992a). Conceptual difficulties experienced by senior high school students of electrochemistry: Electric circuits and oxidation-reduction equations. *Journal of Research in Science Teaching, 29,* 121-142.
Garnett, Pamela J. and Treagust, D.F. (1992b). Conceptual difficulties experienced by senior high school students of electrochemistry: Electrochemical (galvanic) and electrolytic cells. *Journal of Research in Science Teaching, 29,* 1079-1099.
Garnett, Patrick.J., Garnett, Pamela.J. and Hackling, M.W. (1995). Students' alternative conceptions in chemistry: A review of research and implications for teaching and learning. *Studies in Science Education, 25,* 69-95.
Garnett, Patrick J. and Tobin, K. (1989). Teaching for understanding: Exemplary practice in high school chemistry. *Journal of Research in Science Teaching, 26,* 1-14.
Gilbert, J.K. (1983). *Alternative Conceptions: Which Way Now?* Paper presented at the AAPT winter meeting, New York.
Griffiths, A. (1994). *A Critical Analysis and Synthesis of Research on Students' Chemistry Misconceptions.* Paper presented at ICASE, Hong Kong.
Hackling, M.W. and Garnett, Patrick J. (1985). Misconceptions of chemical equilibrium. *European Journal of Science Education, 7,* 205-214.
Hewson, P.W. (1981). A conceptual change approach to learning science. *European Journal of Science Education, 3,* 383-396.
Hewson, P.W. (1996). Teaching for conceptual change. In D.F.Treagust, R.Duit and B.J.Fraser (Eds) *Improving Teaching and Learning in Science and Mathematics.* New York: Teachers College Press, p. 131-140.
Hill, D. (1988). Misleading illustrations. *Research in Science Education, 18,* 290-297.
Johnstone, A. (1991). Why is science difficult to learn? Things are seldom what they seem. *Journal of Computer Assisted Learning, 7,* 75-83.
Nakhleh, M.B. (1992). Why some students don't learn chemistry. *Journal of Chemical Education, 69,* 191-196.
Novak, J.D. (1978). An alternative to Piagetian psychology for Science and Mathematics Education. *Studies in Science Education, 5,* 1-30.
Posner, G., Strike, K., Hewson, P. and Gertzog, W. (1982). Accommodation of a science conception: Towards a theory of conceptual change. *Science Education, 66,* 211-227.
Roth, W.M. (1993). Construction sites: Science labs and classrooms. In K.Tobin (Ed) *The Practice of Constructivism in Science Education.* Washington, D.C.: AAAS Press, p. 145-170.
Solomon, J. (1994). The rise and fall of constructivism. *Studies in Science education, 23,* 1-19.
Tobin, K. and Tippins, D. (1993). Constructivism as a referent for teaching and learning. In K.Tobin (Ed) *The Practice of Constructivism in Science Education.* Washington, D.C.: AAAS Press, p. 3-21.
Treagust, D.F., Duit, R. and Fraser and B.J. (1996). Overview: Research on students' preinstructional conceptions - the driving force for improving teaching and learning in science and mathematics. In D.F.Treagust, R.Duit and B.J.Fraser (Eds) *Improving Teaching and Learning in Science and Mathematics.* New York: Teachers College Press, p. 1-14.

von Glasersfeld, E. (1993). Questions and answers about radical constructivism. In K.Tobin (Ed) *The Practice of Constructivism in Science Education.* Washington, D.C.: AAAS Press, p. 23-38.
Vygotsky, L. (1986). *Thought and Language*. Cambridge MA: MIT Press.
Wandersee, J.H., Mintzes, J.J. and Novak, J.D. (1994). Research on alternative conceptions in science. In D.L. Gabel (Ed) *Handbook of Research on Science Teaching and Learning*. New York: Macmillan, p. 177-210.

# USING INTERACTIVE MULTIMEDIA TO ENHANCE BEGINNING STUDENTS' UNDERSTANDING OF CHEMICAL EQUATIONS

**Patrick J Garnett**, **Mark W Hackling and Ron Oliver**

*Edith Cowan University, Joondalup, Western Australia 6027*

## Abstract

This paper describes the development of interactive multimedia materials designed to improve beginning students' understanding of chemical equations. The materials make extensive use of the graphical and interactive facilities of multimedia to provide an environment that supports the development of students' concepts and skills relating to chemical equations. The materials include three modules dealing with molecular equations, ionic equations and interpreting equations. In the first two modules students explore a range of chemical reactions from three perspectives: macroscopic (video footage of each reaction), submicroscopic (an interactive computer simulation of molecular behaviour during each reaction), and symbolic (balancing chemical equations). The module on interpreting equations develops students' skills by providing them with quantitative exercises that require them to work with equations at a particulate level.

## Introduction

### Alternative conceptions research

Reviews of alternative conceptions research (Garnett, Garnett & Hackling, 1995; Nakhleh, 1992) indicate that it is difficult for introductory chemistry students to develop adequate conceptions of the unobservable entities (atoms and molecules) and events involved in chemical reactions. The difficulties students experience visualising the submicroscopic particulate nature of matter and the processes involved in chemical reactions represent a major barrier to the development of a scientifically valid understanding of many chemistry concepts. As a result, beginning students often exhibit a range of alternative conceptions about the molecular basis of chemical reactions and this subsequently affects their ability to write balanced equations, interpret the symbolic representations used in equations and solve problems based on equations.

Studies of students' understanding of chemical formulas and equations and what they represent indicate that many students have a limited understanding of the meaning of formula subscripts and equation coefficients and do not appreciate the particulate basis and dynamic nature of chemical reactions (Garnett, Hackling, Vogiatzakis & Wallace, 1992; Friedel & Maloney, 1992; Schmidt, 1990; Ben-Zvi, Eylon & Silberstein, 1987; Yarroch, 1985).

In an American study Yarroch (1985) found that only about half the students in a Year 12 sample who were able to balance chemical equations were able to draw a reasonable diagrammatic representation of the equation at a particulate or molecular level. Students often drew representations which, while consistent with the total number of atomic particles involved, were inconsistent with the formulas of the substances involved and the coefficients in the equation. Yarroch concluded that many students had inadequate conceptions regarding the meaning of formula subscripts and equation coefficients.

Students often regarded these as numbers distinguished by their location in an equation, and used to balance the numbers of atoms on both sides of the equation, but had little understanding of their chemical significance.

Ben-Zvi, Eylon and Silberstein (1987) reported that many Israeli students also held inappropriate conceptions about both structural and interactive aspects of chemical reactions. Students commonly represented the molecular compound $Cl_2O$ as two fragments, $Cl_2$ and O, and failed to distinguish between $N_2O_2$ and $N_2 + O_2$ when considering possible products of a reaction between $N_2$ and $O_2$. Student difficulties with the interactive nature of chemical reactions are illustrated by the reaction between $N_2$ and $O_2$. Some students thought $N_2O_5$ could not be formed because of the need for three additional O atoms, while others thought NO could not be formed because the mass of the products would be less than that of the reactants.

In a study involving Year 10 Australian students Garnett et al. (1992) reported that many students displayed limitations in their ability to balance chemical equations and apply an understanding of equations to 'simple' stoichiometry problems. Students were often unable to draw diagrammatic representations of equations and many showed a lack of understanding of the different meanings of formula subscripts and equation coefficients.

It is clear that many students lack a conceptual understanding of the submicroscopic particulate nature of matter and the changes represented by chemical equations. In addition, Andersson (1986) and Ben-Zvi et al (1987) identified students who held a 'static' rather than 'dynamic' understanding of chemical reactions. These students failed to visualise chemical reactions as dynamic processes in which particles/molecules react to produce new particles/molecules by rearrangement of atoms through breaking bonds and forming new bonds.

The difficulties students experience because of the abstract, unobservable, particulate basis of chemistry has been previously described within a Piagetian epistemological framework (Herron, 1978). Several authors have advocated the use of concrete models to help students better understand the nature of matter (Garnett, Tobin & Swingler, 1985; Gabel & Sherwood, 1980; Herron, 1978). Modern multimedia technology has considerable potential to provide students with simulations of the submicroscopic/particulate nature of matter in its various states and the processes underlying physical and chemical change.

### Chemistry at the macroscopic, submicroscopic and symbolic levels

Johnstone (1991) has proposed that chemical change is represented in three modes or levels. These are:

- The macroscopic level, which is sensory and deals with tangible and visible phenomena, eg. salt dissolving in water
- The submicroscopic level, which provides explanations at a particulate level, eg. disruption of the ionic lattice with ions, surrounded by water molecules, moving into solution
- The symbolic level, which represents processes in terms of formulas and equations, eg. $NaCl(s) + H_2O(l) \rightarrow Na^+(aq) + Cl^-(aq)$

Johnstone believes that insufficient attention is given to understanding chemistry at the submicroscopic level and has pointed out the difficulty for students when teachers move quickly between these different levels. From the available research evidence it appears that students have most difficulty in dealing with the submicroscopic which is, of course, outside their experience and can only be made accessible to students through the use of models, analogies or computer graphics.

### Computer based instructional materials

Interactive multimedia (IMM) describes an instructional technology with a number of critical attributes (Jonassen, 1988). In particular, IMM provides multiple media forms to represent information, opportunities for high levels of student engagement, and contextual feedback in response to student input. IMM technologies are able to provide learning environments that are self-paced, learner centred and flexible, cater for individual differences and offer a collaborative learning environment.

Interactive multimedia materials are eminently suited to the simulation of chemical processes using dynamic graphical representations of molecular interactions. Tasker, Chia, Bucat and Sleet (1996) and Russell, Kozma, Jones, Wykoff, Marx and Davis (1997) have reported recently on the development of molecular animations of a range of chemical processes aimed at improving students' understanding of the submicroscopic/molecular basis of these processes.

## Description of the project

### Materials

This project developed an IMM package designed to help beginning students understand the particulate basis of chemical reactions and their symbolic representation as chemical equations, and to apply this understanding when balancing equations and solving simple problems based on equations. In particular, the materials were designed to:

- assist students to link the three levels of chemical knowledge described previously, ie. the macroscopic, submicroscopic and symbolic levels
- provide students with an understanding of the particulate basis of chemical reactions
- help students understand the dynamic nature of chemical reactions
- provide opportunities for students to learn and practise the skills of balancing chemical equations
- develop students' skills in interpreting chemical equations at a quantitative level
- develop an understanding of the concept of limiting reagent

The materials were designed for use in lecture, tutorial and self-instructional modes.

The project has developed three discrete modules that introduce students to chemical equations and develop skills in balancing equations and their interpretation. Two modules deal separately with molecular and ionic equations . A third module provides students with practice in the interpretation of equations.

Modules 1 and 2 both include instruction for eight chemical reactions. For each of these eight reactions students can:

1. View a video demonstration transformed into computer images. These images were intended to show students the actual appearance of a reaction when it occurs in real life. The purpose of this macroscopic view was to provide a link between the real world and the submicroscopic/particulate models chemists use to interpret chemical reactions.

2. View a simulation of the reaction at a particulate level. These animations use dynamic graphics that illustrate the behaviour of atoms and molecules and the transformations they undergo in chemical reactions. The animations were designed to represent, at a particulate level, the processes that occur during chemical reactions using information that is available about these processes. In some examples, where these processes are very complex, the process animations were simplified.
3. Write a balanced chemical equation. Equations are used to represent chemical reactions at a symbolic level. Students are provided with a particular approach to the balancing of equations which enables them to scaffold their knowledge. In this interactive program students are provided with a word equation and are asked to enter the formulas of each of the substances involved. Feedback is provided in relation to the chemical formulas written and also on the coefficients used to balance the equations. An option allows students to enter the physical states of all the substances involved.

Sets of twenty additional reactions are provided with both these modules to give students further practice in writing balanced chemical equations.

In Module 3 students develop their understanding of what chemical equations represent and their skills in interpreting equations. They are asked to interpret equations by drawing "before" and "after" diagrams to represent what occurs in a chemical reaction, do simple calculations to develop an understanding of the meaning of coefficients in chemical equations, and write equations to represent reactions illustrated by "before" and "after" diagrams. The concept of limiting reagent is introduced in some sections of this module.

## Project management

The project management team consisted of three members who collectively had knowledge and skills in chemistry, science education, interactive multimedia development and instructional design. The development team also included personnel with the following areas of expertise: graphics design, programming, video production and video digitising.

The materials were designed to be across-platform, and a hybrid CD-ROM has been developed which can be operated in both Macintosh and Windows environments. The videos and some molecular simulations are Quicktime movies while other simulations are Macromedia Director animations. The balancing and interpreting equations exercises were constructed in Macromedia Director.

## Issues of content in the design of the materials

During its development phase the project developers were confronted with several interesting challenges. These included:

- Selection of reactions where the materials contain a representative selection of reactions encountered in introductory chemistry courses including the following: reactions between gases, metal with oxygen, decomposition, precipitation, acid with base, acid with metal oxide, acid with carbonate, acid with metal, metal displacement and halogen displacement
- Designing the materials to assist students make connections between the symbolic and submicroscopic representations of chemical reactions
- Designing activities that enhance students' skills in interpreting equations eg. simple interpretation of equation coefficients, interpretation of equations using numbers of species that are simple multiples of equation coefficients, interpretation of equations involving limiting reagents, and developing equations from diagrammatic representations

- Establishing the current state of knowledge concerning mechanisms of chemical reactions at the submicroscopic/particulate level - this knowledge is often limited
- Making compromises between scientific accuracy and student sophistication
- Programming difficulties such as the use of subscripts and superscripts which was overcome using fontmonger to create a purpose-specific "chemfont"
- Developing appropriate feedback strategies to match likely student difficulties
- Representing hydrogen ions and proton transfer processes
- Representing electron transfer processes
- Making compromises between illustrating vast numbers of molecules and focusing student attention on reacting species
- Representing relative atomic/molecular sizes

## Features of the IMM materials

Use of illustrations and dynamic graphics

The program was designed to make extensive use of video illustrations and animations using dynamic graphics. From a cognitive perspective, graphics have been found to help learners focus their attention on explanative information and to aid them in organising information into useful mental models (Mayer, 1989). In addition, the dual-coding theory (Paivio, 1979), which recognises independent visual and verbal coding mechanisms in long term memory, suggests that visual imagery is more likely to be dually coded than verbal information.

Learner interactivity and engagement

The program was planned with a number of opportunities for learner interactivity and engagement. Constructivist epistemologies value learner-centred activities that facilitate personal involvement in knowledge construction through students' cognitive activities (Lebow, 1993; Reeves, 1993). In multimedia environments, interactivity that leads to high levels of cognitive engagement appears to be an important aspect in achieving this involvement.

Feedback routines were carefully planned to encourage reflection among learners and to anticipate learning difficulties based on learner responses. Oral feedback was included in certain parts of the program in place of conventional textual feedback. Cognitive load theory (Sweller, 1988) reasons that when viewing computer feedback in several forms, for example, animations and textual descriptions, the tasks create split attention with the learner attending to two discrete information sources. The theory argues that one of the sources can be neglected and the learning becomes inefficient and ineffective. The use of oral and visual feedback can reduce the split attention and lead to enhanced learning outcomes.

Interface design

In most CBL packages learner control is a key element of the instructional design and high levels of learner control are usually considered a positive attribute associated with increased learner motivation and achievement gains. The user interface for this program provided for higher rather than reduced levels of learner control. Some instructional influence over naive users was planned through implementation strategies that included a level of instructor support and scaffolding. The program content was organised in an hierarchical fashion which reflected a recommended instructional sequence but which placed little constraint on users' instructional choices.

## Conclusion

This IMM package was designed to improve students' understanding of the particulate/molecular basis of chemical reactions, and their ability to interpret chemical equations and solve problems based on equations. The provision of concrete representations of unobservable entities and processes, and the use of an interactive approach with associated feedback should facilitate students' achievement of scientifically acceptable conceptions of chemical equations and their application.

## Acknowledgment

Financial support from the Committee for the Advancement of University Teaching is gratefully acknowledged.

## References

Andersson, B. (1986). Pupils' explanations of some aspects of chemical reactions. *Science Education, 70,* 549-563.

Ben-Zvi, R., Eylon, B. & Silberstein, J. (1987). Students' visualisation of a chemical reaction. *Education in Chemistry, 24,* 117-120.

Friedel, A.W. & Maloney, D.P. (1992). An exploratory, classroom-based investigation of students' difficulties with subscripts in chemical formulas. *Science Education, 76,* 65-78.

Gabel, D. & Sherwood, R. (1980). The effect of student manipulation of molecular models on chemistry achievement according to Piagetian level. *Journal of Research in Science Teaching, 17,* 75-81.

Garnett, Patrick J., Garnett, Pamela J & Hackling, M.W. (1994) Students' alternative conceptions in chemistry: A review of research and implications for teaching and learning. *Studies in Science Education, 25,* 69-95.

Garnett, Patrick J., Hackling, M.W., Vogiatzakis, L. & Wallace, T. (1992). *Year 10 students' understandings of chemical equations.* Paper presented at the 9th National Convention, Royal Australian Chemical Institute, Melbourne.

Garnett, Patrick J, Tobin, K. & Swingler, D.G. (1985). Reasoning abilities of Western Australian secondary school students. *European Journal of Science Education, 7,* 387-397.

Herron, J.D. (1978). Piaget in the classroom. *Journal of Chemical Education, 55,* 165-170.

Johnstone, A.H. (1991). Why is science difficult to learn: Things are seldom what they seem. *Journal of Computer Assisted Learning, 7,* 75-83.

Jonassen, D. (1988). *Instructional designs for microcomputer courseware.* Hillsdale, NJ: Lawrence Erlbaum.

Lebow, D. (1993). Constructivist values for instructional systems design: Five principles towards a new mindset. *Educational Technology Research and Development, 41(3),* 4-16.

Mayer, R. (1989). Systematic thinking fostered by illustrations in scientific text. *Journal of Educational Psychology, 81*(2), 240-246.

Reeves, T. (1993). Interactive learning systems as mind tools. In P. Newhouse (Ed), *Educational Computing Association of Western Australia Annual Conference*, 2. Mandurah: ECAWA.

Russell, J.W., Kozma, R.B., Jones, T., Wykoff, J., Marx, N. and Davis, J. (1997). Use of simultaneous-synchronised macroscopic, microscopic and symbolic representations to enhance the teaching and learning of chemical concepts. *Journal of Chemical Education, 74*, 330-334.

Schmidt, H. (1990). Secondary school students' strategies in stoichiometry. *International Journal of Science Education, 12,* 457-471.
Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science, 12,* 257-285.
Tasker, R.F., Chia, W., Bucat, R.B. and Sleet, R. (1996). The VisChem Project - visualising chemistry with multimedia. *Chemistry in Australia, September 1996, 395-397.*
Yarroch, W.L. (1985). Student understanding of chemical equation balancing. *Journal of Research in Science Teaching, 22,* 449-459.

# QUANTUM LEAPS IN CHEMISTRY EDUCATION FOR INDIGENOUS PEOPLE

**Kate Gloury and Greg Williams**

*Faculty of Aboriginal and Torres Strait Islander Studies, Northern Territory University, Darwin N.T. 0909.*

**Abstract**

Despite the fact that indigenous people have their own knowledge of a wide range of materials and sophisticated preparation and processing techniques, access to the strictly codified knowledge of chemistry in a western scientific tradition is often problematic. For us as teachers and educators, an appreciation and understanding of appropriate learning styles is leading to increased access and greater success for indigenous students and consequently others, in their study of chemistry. The support of a culturally safe environment and the establishment of links between bridging and degree programs in science are promoting articulation into higher education of students from diverse cultural backgrounds.

**Introduction**

It is not difficult to understand why few indigenous people are either enrolled in chemistry or working as chemistry professionals in the field. The lifestyle of contemporary and traditional indigenous people often involves a direct knowledge and expert use of chemicals and the application of what could be described as chemical principles. However, when it comes to the formal study of chemistry, generally the material is considered to be, at best important, but inaccessible or simply irrelevant to daily life. This is not surprising when you consider the origins of chemistry and the underlying assumptions of the worldview upon which the study and application of formal chemical principles are based. Chemistry is a science and science is enmeshed within culture. It could be argued that it is now a widely held understanding that learning subjects such as chemistry involves many aspects of language learning including the need to be aware of and understand the associated and inter-relating culture. For a student to learn such a subject successfully, requires us as teachers to develop strategies that make explicit the language of chemistry; the jargon and the cultural assumptions that go along with knowing about the subject material. Combine this with the foreign nature of formal studies at secondary and tertiary institutions and the lack of cultural appropriateness of educational institutions, and it is hardly surprising that so few indigenous people "make it" in either secondary or tertiary science education. The education system in which subjects like chemistry are taught are at odds with the very foundations of indigenous pedagogy where the education process is contextualised within the culture. At the Faculty of Aboriginal and Torres Strait Islander Studies of the Northern Territory University, the aim of our Higher Education Preparatory Program in Maths and Sciences (HEPPMS) is to establish a learning environment where indigenous students feel secure in accessing formal studies in science. The languages of science (and chemistry in particular) are made explicit and accessible, and students are encouraged and supported in their moves towards studies in science in higher education.

**Chemistry as Language and Culture**

The difficulties that arise in learning a subject such as chemistry stem mainly from the cultural embeddedness of the subject material and its traditional modes of delivery. Chemistry as a scientific discipline is a product of the Enlightenment period of history, based in the western scientific tradition and studied and taught, on the whole, by people who subscribe to that worldview - one based on atomistic and objectivist notions of reality (Christie 1992: 14-15). The discipline is a product of its own history and is constrained by the very processes, events of history and personalities that created it. It is important to identify and make explicit this culture of chemistry and its expression within the classroom. Just as it is important to recognise and value the background and life experiences brought to the classroom by the learner (Wittrock 1994), so too is it important to recognise the history and background of the subject material, to enable learners to navigate more effectively through the content.

The language of chemistry is a language of jargon (as are most specialised subjects) and a formal study of the subject is stacked full of terms, phrases, procedures and conventions that have a coherent meaning usually only within the context of that study. Common words and phrases often have vastly different meanings when used in a chemistry context. There is essentially no problem with this! Chemistry deals with abstract concepts and the evolution of new concepts requires the development and use of new language to allow chemists to interact easily at new conceptual levels. It is important however, that this is clearly understood to be the case before beginning to attempt to involve others in the learning process.

Chemistry language learning is happening constantly and in a variety of ways within the classroom. Often, students are expected to learn new concepts and underlying language by some process of osmosis. To a greater or lesser extent, many teachers provide information, skills (and language to varying degrees) to students, who then take the materials away and attempt to decipher it on their own and amongst peers. In effect the students are trying to translate the new material into linguistic forms that are familiar to their own experiences. Our experience suggests that when you provide an explanation to students which helps them to understand what it is they are actually doing, so that they are explicitly aware of the linguistic nature of learning chemistry, rates of student success and levels of student satisfaction are much higher. By providing appropriate scaffolding experiences and modeling how the language of chemistry can be translated, you give students familiar strategies by which they can begin to establish a sense of how to approach learning the subject material.

*'Some teachers and some students see chemistry as consisting of avenues that each of us can take as we try to make sense of a part of the physical world. Each student builds a base of understanding and can then go on to make sense of the idea of atoms, molecules and all the chemistry that is opened up.'* (Barrow 1997 p 1154)

Students need a clear structure upon which to develop their conceptions of the subject rather than the 'alchemy' and mystique of chemistry education of the past (Johnstone 1997).

**Flexible Delivery**

As is usually the case, the dilemma in tertiary bridging education is one of balance. There is a fine line somewhere between instituting the pressures of structures deemed necessary to prepare students for higher education chemistry and the time and flexibility needed to allow students to access new material, understand the rigors of tertiary study and cope with the new stresses of tertiary student life. Our experiences suggest that our science bridging programs are more successful in providing students with a strong grounding in the subject material and confidence in their own ability to tackle the challenges of a degree program when they focus upon the need for adaptability and flexibility. We strive to reflect this in the strategies we use to allow students time to explore the ideas that are presented and develop and consolidate basic skills without many of the external university pressures. Our aim is to ensure that students feel secure enough to be willing to take intellectual risks in their learning.

The aim is to ensure that chemistry classes are as experiential as possible. When students are able to make contact with the real 'stuff' of chemistry and see for themselves the macroscopic results of chemical processes, they are provided with visual keys to assist in the chemical language translation process. Regularly in our chemistry classes, impromptu demonstrations are provided as discussion develops in certain directions. There is a certain spontaneity in the way classes are run when matters arise which can be demonstrated by some practical activity. Many of the issues raised provide opportunity for students to develop their mapping of chemical concepts - assist students to develop pictures of how chemistry works that will help them make sense of the abstract and unseeable that constitutes chemical theory. They may need to create completely new pictures as their understanding of chemistry broadens and develops, but at least they will be attuned to doing so and recognise and accept it as a valid learning apparatus.

Limited time frames for learning require an administrative balancing act between the timetable and the pedagogical need for un-hurried and un-pressured learning. To circumvent this potential conflict, our courses have appropriated the timetable in as many ways as possible including running classes over both one year and six months, impromptu tutorial sessions and free access to lecturers outside designated class times. Students who are able to pick up concepts quickly, move through the program in a shorter period of time, whilst those who arrive with little background in science, can take up to a year to familiarise themselves with the language of chemisty, using the full gamut of learning environments to facilitate this. The aim is to ensure that the learning experiences of the students and *their* needs drive the timetable and administration procedures, rather than the other way around.

Mathematics is often a key obstacle for students enrolling in chemistry classes and our strategy is to approach the subject material from a strongly qualitative perspective. We leave the mathematics out of the curriculum until students feel comfortable with the chemistry and then introduce it where it is necessary and increasingly as students feel confident with its use. The key with mathematics is to use strategies that work rather than focussing on the principles behind the mathematics. The aim to contextualise the mathematics and use it as a tool for deriving useful answers rather than an end in itself. Hence, students are exposed to a wide range of memory aiding devices and short-cut methods that work and can be explained when necessary.

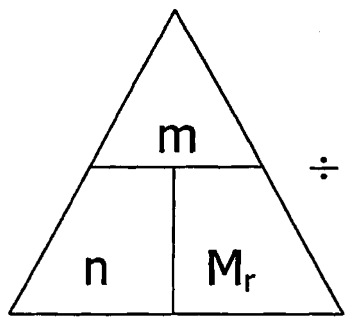



Figure 1: Chemical Formula Pyramid: A useful aid in circumventing many of the probems of mathematical formula re-arrangement.

The thumb is placed over the symbol for the quantity which is to be the subject of the mathematical enquiry. The resulting equation is the algebraic formula required to solve the problem. Students learn to use the units of each quantity to check their answers at the same time.

Most of the students are involved in studying mathematics at the same time as chemistry and often the content overlaps. In many cases the same lecturer may have input into both classes and therefore it is easy to indicate the application of the mathematics within the other science classes.

Additionally, the well known and discussed benefits of smaller classes, individual attention, proactive tutorial support (both from the lecturer and through the Aboriginal

Tutorial Assistance Scheme - ATAS) and accessibility of teaching staff are important aspects of the culture of the institution, all of which contribute to the development of an encouraging, learning environment while minimising undue stress. Proactive tutorial support involves getting to know the students, anticipating problems they may have and prepare strategies to circumvent difficulties and to help regain confidence afterwards.

The program of support doesn't stop when students leave the HEPPMS program. Support is provided in a number of practical ways to assist students enrolled in higher education science programs which involve chemistry. Regularly staff members are co-opted by the Faculty of Science to contribute to the running of the introductory chemistry units where indigenous students are able to relate to familiar faces, providing some continuity to their study program across the university. Indigenous students still have access to the ATAS scheme and are free to use this program for both remedial and pro-active support.

**Environment**

Many of the teaching strategies used in our Higher Education Preparatory Program have application across the spectrum of cultures and are not specifically designed to prepare indigenous chemistry students. However, the broader environment in which the chemistry learning takes place has a more culturally specific tenor. By developing a Higher Education Preparatory Program within the Faculty of Aboriginal and Torres Strait Islander Studies, we aim to provide an environment which is culturally safe. The indigenous students own the program. It belongs to them and others who enrol in the program are meeting indigenous students on their 'country'. The indigenous students are not in the minority and as such are more immune to apprehension caused by the structures of the university (or school) system and the subject material. The environment is a crucial aspect of the success of the program. By recognising the needs of indigenous students, catering for them specifically and providing the opportunities for success within their personal and social constraints, students are able to see that there is the possibility of learning about science and chemistry. An opportunity arises for students to see that chemistry doesn't need to be a barrier to careers as scientists, nurses, doctors and other professions often the seemingly exclusive domain of non-indigenous people.

**Access**

Chemistry education at a pre-tertiary level is becoming increasingly necessary as employers and other educators recognise the significance of developing a basic appreciation of the principles and practical skills associated with chemistry. In a majority of universities, science and nursing desgrres expect some level of proficiency in basic chemical theory. Students entering the Higher Education Preparatory Program in Maths and Science and the chemistry units in particular, come from a variety of backgrounds and enrol for a variety of reasons. Those attracted to the course include students who have had minimal success in sciences at secondary school or who simply have not had the opportunity to attend full secondary education. They include mature-age students wishing to change career, upgrade qualifications and those who simply want to extend their education. School leavers who require a chemistry background for courses often enrol to achieve qualifying grades. Students come from a wide variety of cultural backgrounds, particularly indigenous Australians from both remote and urban areas and lately, non-indigenous Australians, some for whom English may not be a first language. Understandably, difficulties that non-indigenous students face in learning chemistry are mirrored to a degree in the issues faced by indigenous students and it would make sense that many of the appropriate teaching strategies described above would be successful irrespective of cultural background.

It is clear that the intention of the Higher Education Preparatory Program chemistry units is to provide sound initial chemical education to students who have been educationally disadvantaged and particularly for those with an indigenous cultural background. Have we succeeded? More to the point, how do we measure success? Quantitatively, it may seem that the success we aim for has been elusive. Many students who appear to be succeeding in chemistry and other units leave without completing units for a variety of reasons. Some students succeed in chemistry units but choose not to continue with further education and others continue on to Higher Education, dropping out for the same variety of reasons, whilst others successfully complete their chosen programs in the same or different universities.

Nevertheless in the time that the program has been running at the Northern Territory University, a significant number of student have completed the course and moved on into higher education and careers in science as is indicated by the table below. Students from our course have excelled in their higher education studies in chemistry (perhaps in spite of their training) including one student who won an RACI award for the best chemistry student in 1997. Success, although not overwhelming is however encouraging with students going on to Associate Diploma and degree courses in Science, Information Technology, Engineering or Nursing.

| Subsequent Career or Study Moves for Students enrolled in HEPPMS | Number of Students |
|---|---|
| Successfully completed the program and moved into:<br><br>TAFE/VET Education<br>Higher Education<br>Work | <br><br><br>1<br>13 (+9)<br>4 |
| Sucessfully completed the program, not involved in further education, work or have been untraceable | 9 (+10) |
| Not successfully completed the program. | 26 (+7) |
| **Total number of students enrolled in the course.** | **53 (+26)** |

Table 1: Subsequent Career and Study Moves for Students Enrolled in the Higher Education Preparatory Program in Maths and Science (HEPPMS) at the Northern Territory University 1991 - 1997.

Speaking to past and present students involved in the program indicates that they do feel secure and confident of their own abilities; two important factors for success in any field. It is also obvious that many students do not start out that way. Many have commented that their ownership of the course is important to them and they feel that it is an important component of their success, particularly when faced with large number of students participating who aren't indigenous. Those students who do take advantage of the articulation of chemistry programs do receive on-going support from the faculty and often achieve high standards in their chosen fields

As a faculty our aim is to provide services both to the indigenous community and to the community at large and we consider that the Higher Education Preparatory Program in Maths and Sciences does in fact provide a valuable service in preparing both indigenous and non-indigenous students for higher education study. By being explicit about the learning process, recognising the cultural embeddedness of the subject material and supporting students as and before difficulties arise, we begin to create an environment which allows for risk taking in learning and confidence in approaching subjects which may at first appear alien. Positive responses from students and continued academic achievement in science of significant numbers encourages us to continue developing the course and identifying ways in which to draw interested indigenous students into chemistry and therefore, perhaps other scientific fields of study.

**References**


Barrow GM (1997) An Essential Recognition: Two Valid Introductory Chemistries *Journal of Chemical Education,* vol.74, no10, p1154.

Christie MJ (1992) *Grounded and Ex-centricKnowledges: exploring Aboriginal Alternatives to Western Thinking,* presented to the Fifth International Conference on Thinking, Townsville, Queensland, July.

Johnstone AH (1997) Chemistry Teaching - Science or Alchemy? *Journal of Chemical Education,* vol.74, no3, pp 262 - 268.

Wittrock MC (1994) Generative Science Teaching, In Fensham P, et al (eds) *The Content of Science: A Constructivist Approach to its Teaching and Learning*, Falmer Press, London.

# ENHANCING STUDENT UNDERSTANDING OF CHEMISTRY CONCEPTS: BRIDGING THE GAP USING A CONCEPTUAL TYPOLOGY OF MULTIPLE MODELS

Allan G. Harrison

Central Queensland University

## Abstract

Modelling is the essence of scientific and technological thinking and models are both the methods and products of science and technology. But how do secondary students view models? Usually as toys or miniatures of real-life objects with few students actually understanding why multiple models are used to explain concepts. A conceptual typology of models is presented and explained to help teachers select models that are appropriate to the cognitive ability of their students. The article concludes by recommending that teachers model scientific modelling to their students by encouraging the use of multiple models in chemistry lessons.

## Introduction

Chemistry students need to become competent modellers if they are to understand and manipulate the models that permeate chemistry lessons and textbooks. This immediately raises the question of "What is modelling?" Modelling can either be a multi-step problem solving process or it can refer to specific models like atomic and molecular models, graphs and equations. Indeed, iconic symbols and chemical formulae (e.g., $CO_2$) have been used so frequently for so long that they have become part of chemistry's language. But how do chemistry teachers use these concept-building analogical models? Do they explain the shared and unshared model attributes or do they leave students to work this out for themselves?

In chemical education, the terms "model" and "modelling" are quite ambiguous: a model may represent a concrete object or process (e.g., a chemical bond), an algorithm for balancing a redox equation, a system for classifying acids and bases or a teaching–learning process like the models for teaching with analogies. These terminological differences lead to semantic and real confusion when the terms "model" and "modelling" are used in unqualified ways. When a teacher reads or hears the word "model", s/he must ask the question, Is it concrete or abstract?, Is it a process or a behaviour? If differences in the way "model" is used for symbols, processes and strategies challenges teachers, how much more confusing is unqualified "model" use for teenage students? Indeed, do students consistently share the teacher's understanding about a particular model?

This paper is, therefore, interested in the ways "models" and "modelling" are used in science and technology lessons and asks the question, How do secondary students perceive the models that feature in textbooks and teacher explanations? In trying to make sense of models and modelling, the paper has two interests: It proposes that modelling is a sophisticated thinking process that should be an explicit part of the curriculum, and, it argues that teachers should be sensitive to the similarities and differences between the models that they use in their explanations.

### *Models and Reality*

There are good reasons to believe that many science students view models as reality and that student modelling often is more algorithmic and instrumental than relational. The positive view, however, is that research conducted by Finster (1989) and Grosslight et al. (1991)

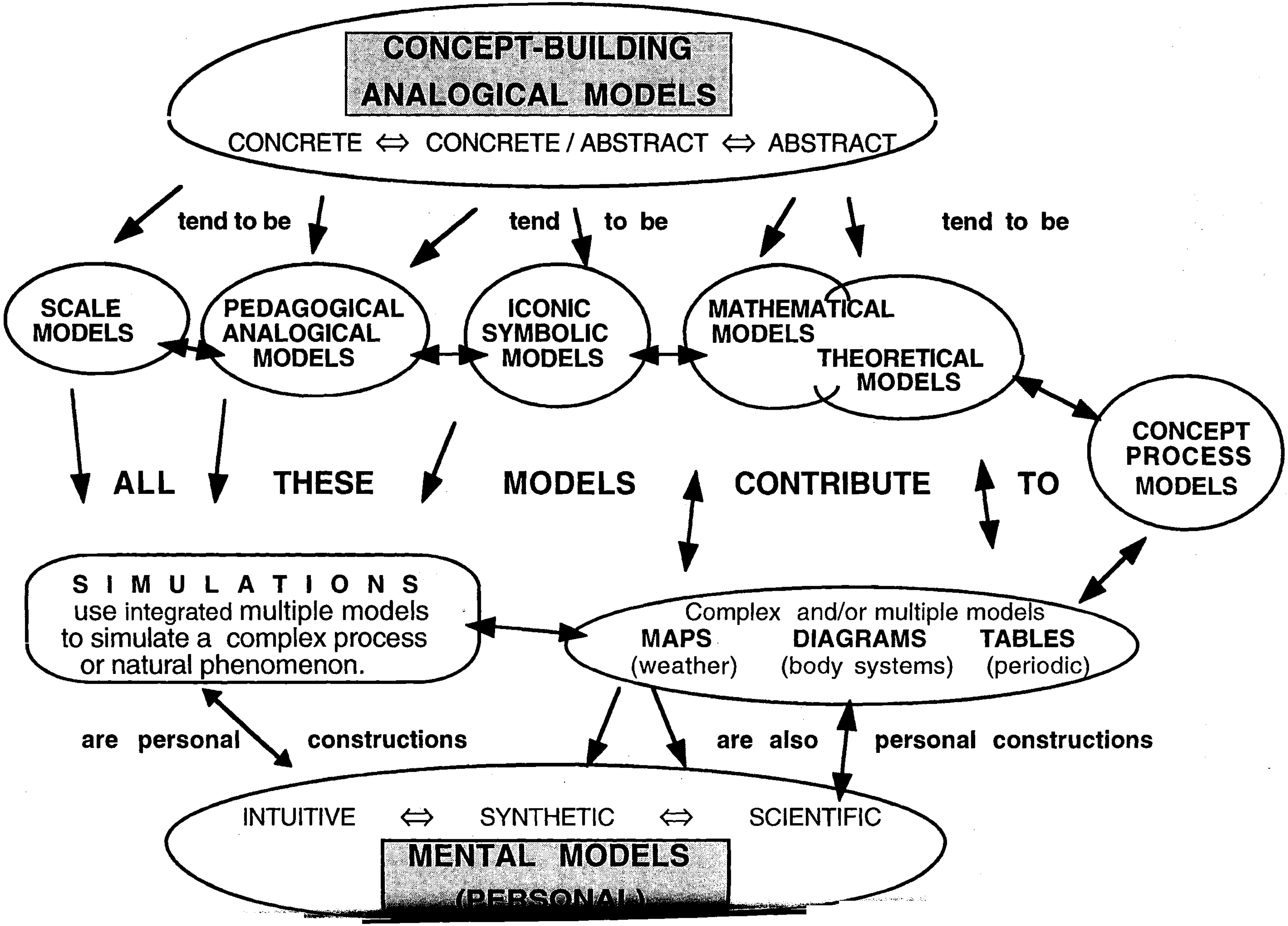



*Figure 1: A relationship between concept building models and student mental models.*

show that students can learn to think critically and creatively. Furthermore, empirical studies in secondary science classes show that students can learn to think in sophisticated ways at an earlier age than was previously thought possible. A useful recent finding is that Grade-11 chemistry students who became creative multiple modellers realised that no model is wholly right and appreciated that science is more about processes than objects (Harrison, 1996).

*Modelling in School Chemistry Lessons*

Various studies show that school students and some teachers think about science models in mechanical terms and believe that 'scientists know the answers' (S. Gilbert, 1991). But models are not 'right answers', models are simultaneously the methods and the products of science and it is quite impossible to teach and learn science without using models (J. Gilbert, 1993). How can we describe or explain atoms, molecules and chemical reactions, without using one or more models? Teachers regularly use models to explain immaterial phenomena like periodic element properties, reaction rates, equilibrium and electron flow. What do teachers do when they see the worried looks on their students' faces in the middle of an explanation about an abstract concept? They reach for an analogy or model and this explains the frequent occurrence of analogical models and diagrams in chemistry lessons.

This paper now presents a typology of concept-building analogical models designed to highlight the similarities and differences existent in the models that teachers use in chemistry. The typology is offered to alert teachers and writers to the variety of models that may confuse some of their audience. The main categories in the model typology are represented in Figure 1 which is a concept map of concept-building analogical models.

## A Typology of Analogical Models

*Concrete and Concrete / Abstract Models Designed to Represent Reality*

*1. Scale models.* Scale models of animals, cars and boats are used to depict colours, external shape and structure. They carefully reflect external proportions but rarely show internal structure, functions or use (Black, 1962).

*2. Pedagogical analogical models.* One or more target attributes dominates the analog's concrete structure; e.g., ball-and-stick and space-filling molecular models or a model eye. As analogical models reflect point-by-point correspondences between the analog and the target for a few attributes, they can be oversimplified and enhanced to highlight those concepts.

*Abstract Models Designed to Communicate Theory*

*3. Iconic and symbolic models.* Chemical formulae and chemical equations are symbolic models of compound composition and chemical reactions. Formulae and equations are so embedded in chemistry's language that school students and non-specialist teachers mistake them for reality when they are, in fact, explanatory and communicative models.

*4. Mathematical models.* Physical properties, changes and processes (e.g., $k = PV$), can be represented as mathematical equations and graphs that elegantly depict conceptual relationships.(e.g., Boyle's Law, exponential decays, etc.).

*5. Theoretical models.* Analogical representations of electro-magnetic lines of force and photons are *theoretical* because the models are human constructions describing theoretical entities. Model theoretical explanations like the kinetic theory model for gas volume, temperature and pressure also belong to this category (Zumdahl, 1989).

*Models Depicting Multiple Concepts and/or Processes*

*6. Maps diagrams and tables.* These models represent patterns, pathways and relationships that are easily visualised by students. Examples are the periodic table, phylogenetic trees, circuit diagrams, food chains, webs and pyramids.

*7. Concept-process model.* Most science concepts are processes rather than objects and this is a major explanatory dilemma: How do teachers explain immaterial processes to students, most of whom think in concrete terms? Teachers use concept-process models like the multiple models of acids and redox (Carr, 1984). Concept-process models often comprise multiple pedagogical, analogical and theoretical models.

*8. Simulations.* Are a unique category of multiple dynamic models simulating highly sophisticated processes like reaction mechanisms. Simulations let novices and researchers develop skills and knowledge without risking life and property and also may include 'virtual reality' experiences, e.g., computer games, interactive multimedia.

*Personal Models of Reality, Theories and Processes*

*9. Mental models.* Mental models are intrinsic descriptions of objects and ideas that are unique to the knower and arise and evolve "through interaction with a target system" (Norman, 1983, p. 7; Vosniadou, 1994). Mental models are highly personal, dynamic and difficult to access. Mental models often include synthetic models.

*10. Synthetic models.* Vosniadou (1994) used this term to describe the evolving alternative conceptions students' synthesise as they meld their intuitive model with their teachers' scientific model. Synthetic models are a common product of science lessons.

**Models and Analogical Reasoning**

Of the models used to represent science concepts, analogical models are frequently used to model macroscopic, microscopic and symbolic entities (Gabel et al., 1992). Analogical models can be concrete (e.g., the camera analogy for the eye ), abstract (a simple tube for an earthworm's gut) or mixed (a ball-and-stick molecular model - Keenan et al., 1980). Analogical models are simplified and enhanced in some way to emphasise the attributes shared between the analog model and the target concept. Despite careful planning to reduce the unshared attributes, analogical models always break down somewhere. Two types of analogy operate between the analog model and the target concept: surface similarities that quickly attract students to the intended analogy and deep systematic process similarities that develop conceptual understanding. The desired concept learning almost always lies in the systematic process similarities and students usually need guidance in mapping these links (Gentner, 1983).

Models only act as aids-to-memory, explanatory tools and concept-learning devices if they are easily understood and remembered by students. Analogical models need to be familiar, logical and owned by the students. Ownership, seems to be strongest when students generate their own analogies; however, reports of student-generated analogies are rare and only Cosgrove (1995) reports success at this level. Students more easily map self-generated analogies than teacher-supplied analogies because their personal analogies are more familiar and easier to apply (Zook, 1991). However, students find it hard to generate or select appropriate analogies for a given problem and are more likely to apply an analogy to a problem when the teacher supplies the analog even though they find mapping it difficult.

This highlights the need for teachers to systematically plan model and analogy use in their lessons and recommends the use of an approach involving the focus, action and reflection (FAR) aspects of expert teaching (Treagust et al., 1998). Focus involves pre-lesson planning where the teacher focuses on the concept's difficulty, the students' prior knowledge and ability and the analog model's familiarity. Action deals with the in-lesson presentation of the familiar analogy or model and stresses the need to map the shared and unshared attributes. Reflection is the post-lesson evaluation of the analogy's or model's effectiveness and identifies modifications necessary for subsequent lessons or next time the analogy or model is used. The FAR guide is outlined in Figure 2.

| | |
|---|---|
| **FOCUS** | |
| CONCEPT | Is it difficult, unfamiliar or abstract? |
| STUDENTS | What ideas do the students already know about the concept? |
| ANALOG | Is it something your students are familiar with? |
| **ACTION** | |
| LIKES | Discuss the features of the analog and the science concept. Draw similarities between them. |
| UNLIKES | Discuss where the analog is unlike the science concept. |
| **REFLECTION** | |
| CONCLUSIONS | Was the analogy clear and useful, or confusing? |
| IMPROVEMENTS | Refocus as above in light of outcomes. |

*Figure 2: The FAR guide for teaching and learning with analogies and models.*

*Student Modelling Abilities*

Students are poorer modellers than teachers expect and younger secondary students usually do not look further than a model's surface similarities. Grosslight et al. (1991) studied student–expert modelling abilities in terms of students' *beliefs* about the structure and purpose of models. They classified many lower secondary students as level 1 modellers because these students believe that there is a one-to-one correspondence between models and reality (models are toys or small incomplete copies of actual objects); models should be 'right'; items are missing because the modeller wanted the model that way, and they do not look for ideas or purposes in the model's form. Some secondary students achieve level 2 where models fundamentally remain real world objects or events rather than representations of ideas; are incomplete or different depending on the context; and the model's main purpose is communication rather than the exploration of ideas. Experts alone satisfy level 3 criteria that models should be multiple; are thinking tools; and can be purposefully manipulated by the modeller to suit his/her epistemological needs. Some students fell into mixed level 1/2 and 2/3 classifications. Because the levels are derived from the ways students describe, explain and use models, the levels also provide useful information about the status of student's conceptual development.

Nearly every textbook examined fails to warn its readers that models are human inventions that break down at some point. Teachers also may assume that their students understand the limits of models; however, Grosslight et al. show that this belief is mostly false. This raises a major thinking and learning problem for students. Students need time and help to realise that models are contrived and limited representations of reality and that the legitimacy of multiple scientific models is a function of epistemological expertise.

*Multiple Explanatory Models*

Many science concepts depend on multiple models for their description and explanation. The more abstract and nonobservable a phenomenon, the more likely it will require multiple models (e.g., atoms and molecules, forces and nerve circuits) because each model elaborates but a fraction of the target's attributes. In many cases, the sum of the models is less than the whole phenomenon for two reasons: the concept itself is not fully understood, and the models tend to overlap. There are sound reasons why no single model can fully illustrate an object or process for, if it did, it would be an example not a model. Expert teachers mostly use models to stress and explore important and difficult aspects of a concept and this is best achieved by over-simplifying the model to emphasise key ideas. This is why multiple models are so useful because a series of simplified models can be used to explain, one at a time, the key ideas.

## Conclusion

This article argues that many different teaching models regularly feature in secondary science lessons. Models can range from concrete scale models depicting no more than superficial features through to abstract concept-process models that use multiple models to represent scientific processes. These concept-building analogical models can be arranged in a model typology that helps teachers understand the conceptual demands that different model types place on students. The paper also points out that no single model can ever adequately model a chemical concept, therefore, students should be encouraged to use multiple explanatory models wherever possible. This is best done by teachers modelling multiple modelling in their lessons. Further, a systematic model should be used whenever analogies and models are presented to school students to ensure that the students recognise the importance and limitations of the analogy or model. Research shows that this task is best accomplished by discussing the shared and unshared attributes with the students.Whenever the social learning environment is supportive and multiple models are used, students can rise to the challenge and surprise their teachers.

## References


Black, M. (1962). *Models and metaphors.* Ithaca, NY: Cornell University Press.

Carr, M. (1984). Model confusion in chemistry. *Research in Science Education, 14,* 97-103.

Cosgrove, M. (1995). A case study of science-in-the-making as students generate an analogy for electricity. *International Journal of Science Education, 17, 295-310.*

Finster, D. C. (1989). Developmental instruction. Part 1. Perry's model of intellectual development. *Journal of Chemical Education, 68,* 659-661.

Gabel, D., Briner, D, & Haines, D. (1992). Modelling with magnets. *The Science Teacher, 59,* 3, 58-62.

Gentner, D. (1983). Structure mapping; a theoretical framework for analogy. *Cognitive Science, 7,* 155-170.

Gilbert, J. K. (Ed.) (1993). *Models and modelling in science education.* Hatfield, Herts: Association for Science Education.

Gilbert, S. W. (1991). Model building and a definition of science. *Journal of Research in Science Teaching, 28,* 73-79.

Grosslight, L., Unger, C., Jay, E., & Smith, C. (1991). Understanding models and their use in science: Conceptions of middle and high school students and experts. *Journal of Research in Science Teaching, 28,* 799-822.

Harrison, A. G. (1996). *Conceptual change in secondary chemistry: The role of multiple analogical models of atoms and molecules.* Unpublished Ph.D. thesis, Curtin University of Technology, Perth, Western Australia.

Harrison, A. G., & Treagust (1996). Secondary students mental models of atoms and molecules: implications for teaching science. *Science Education, 80,* 509-534.

Keenan, C. W., Kleinfelter, D. C., & Wood, J. H. (1980). *General college chemistry (6th Ed.).* San Francisco, CA: Harper and Row, Publishers.

Norman, D. A. (1983). Some observations on mental models. In D. Gentner & A. L. Stevens (Eds.), *Mental models* (pp. 7-14). Hillsdale, NJ: Erlbaum.

Treagust, D. F., Harrison, A. G., & Venville, G (1998). Teaching science effectively with analogies: An approach for preservice and inservice teacher education. *Journal of Science Teacher Education, 9,* 85-101.

Zook, K. B. (1991). Effect of analogical processes on learning and misrepresentation. *Educational Psychology Review, 3,* 1, 41-72.

Vosniadou, S. (1994). Capturing and modelling the process of conceptual change. *Learning and Instruction, 4,* 45-69.

Zumdahl, S. (1989). *Chemistry (2nd ed.).* Lexington, MA: D. C. Heath and Company.

# NOW THE GOOD NEWS? - BRIDGING THE GAP TO THE COMMUNITY

**D Brynn Hibbert**

*School of Chemistry, University of New South Wales, Sydney, NSW 2052*

## Abstract

The need for a good public understanding of science is discussed in terms of three approaches: the practical argument, the cultural argument and the political argument. In a world in which increasingly complex science is involved in every day life, it is important that ordinary people have some understanding about the chemical world they live in. There has been a shift away from considering an educated person as one versed not only in the arts but in the sciences too, and many sophisticated people appear to be proud of being scientifically illiterate. Finally, politicians must have a measure of understanding of science and particularly risk assessment when weighing up arguments of how to spend public money.

Bringing 'good news', as typified by the Cochlear prosthetic implant, is one way of combating increasingly negative stories about science. However very few topics are entirely without controversy, and the science communicator must realize this, and be prepared to maintain the rational debate. In the case of the hearing implant, some deaf groups believe that the money is not well spent turning a functioning deaf person into a partially-hearing 'ordinary' person. Funding of research by commercial or political interests also lays a scientist open to accusations of bias brought about by the need to maintain funds in an increasingly competitive world.

Conclusions drawn are that more scientists should enter popular debates as informed citizens, rather than 'men in white coats' and be prepared to face criticism with clear and well-founded arguments. A number of scientifically-literate people offering different views on the issues of the day will counterbalance the worrying trend to 'damnation by assertion' practiced by certain groups in society.

## Introduction

It may be argued that 'science' won the Second World War for the allies, and for a time after 1945 to be a scientist was the aspiration of many of the brightest school children. Indeed the present cohort of academics who are between forty and fifty years old, will have been brought up in a world in which the discovery and exploitation of knowledge about the world was held in high esteem. By the end of the 1970s when science had apparently not delivered the goods of a demonstrably better world for the majority of its citizens, the tide turned with scientists held out to be evil (or at best misguided) megalomaniacs, or lunatics in the pay of government or multinational business. No amount of 'what about ... ' arguments could stop a popular view that tied science in general, and chemistry in particular, with pollution, destruction of the environment and threats to the integrity of the planet. Indeed it is now popular to argue that science is a passing fad of humankind that has done its dash (Gimpel, 1995), or that science is simply another religious construct that has no more special place than the animist religions of the more inaccessible regions of the world. Clever students now are to be found in medicine, law and commerce with the bright idealism of an earlier time giving way to monetary remuneration and a lifestyle far removed from the ethereal academic, innovative inventor or thrusting industrialist.

Understanding the place of science in the modern world is not a trivial exercise. People will not be won over only by careful and reasoned argument in the up-market press, or a popular campaign by the chemical industry. A number of complex and interrelated issues must be grappled with before the scientist is rehabilitated in the world.

This paper discusses arguments for a popular understanding of science, and explores some of the issues related to telling the 'good news' to the public.

## Arguments for a better public understanding of science

If science is misunderstood, and as a consequence is held in low esteem, one of the goals of a movement to reinstate science must be a program of education of the public. Mere abstruse facts and high opinion from scientists is not sufficient. If the average person hated science at school, they are not voluntarily likely to resume their acquaintance with the subject in later life unless they perceive benefit. I offer three arguments on why a non-scientifically trained person should bother to know anything about science.

### The Practical argument

Despite the opinion of sections of the community, the readers of this paper will all live in a country that depends on modern science and technology, and will interact with manufactured chemicals every day. Dr Joe Baker in his keynote "Bridging the Gap to Industry" noted that he had identified 75 chemicals in his bathroom and was still counting. It should be without contention, therefore, that a basic knowledge of chemistry can be useful when purchasing, handling and disposing of every day chemicals. Concepts of acids and bases, of the toxicity of substances and of corrosion would be a knowledge base to start with. Just as early society passed down knowledge of what plants were edible, which could be used medicinally, which required processing to make them safe, modern society needs to have a similar body of knowledge for the present-day materials its people are exposed to.

A basic understanding of chemistry and physics may also protect the public from frauds and scams. It is possible to buy a so-called 'magic plate' in a weekend market in Sydney, Australia, that will clean silver. The plate has strategically-placed holes and it is asserted that in a bicarbonate of soda solution, an item of silver rubbed up against it will have its tarnish removed and silver lustre restored. The plate sells for around $30, and the problem is not that it does not work, but that it is made of a 1 cent piece of aluminium. The electrochemistry that turns aluminium into $Al^{3+}$ and $Ag^{+}$ back into silver metal, is basic redox chemistry, and while a member of the public may not be expected to write the balanced equation, the notion that the process is probably explainable in terms other than 'magic' should be sufficient to drive the price down or send those with dirty silver to a roll of cooking foil (Hibbert, 1993a). This may not be a good example, as the chemistry is not trivial, and a professor of marketing suggested that if the buyers believed it was worth $30 to clean their silver, then a fair trade had taken place.

Despite Julius Meyer's statement of the First Law of Thermodynamics in 1842, the number of inventions that palpably violate this fundamental law of nature increases without check. Whether fraud or a simple misunderstanding, millions of dollars are poured into schemes that are based on the idea that something can come of nothing (Hibbert, 1994). The reporting of such schemes is often ingenuous, with the reader thinking that the energy problem has been solved, or cancer cured. An example is to be found on the front page of the Sydney Morning Herald of 13th September, 1988, of which the headline proclaimed "Water into Fire an Inventor's Triumph", and the article commenced "A cramped workshop at the back of a suburban house in Sydney's west seems an unlikely place to trigger a global energy revolution". The article went on to suggest that within a few years we would be "running our cars from the garden hose". The inventor of the welding machine (!), being given more publicity than money could buy, was calling himself a 'Research Professor'. Thus in the ensuing debate, the public could well have dismissed the argument as between two nutty professors (I was also featured in the article). And when, for example, Professor Hibbert announces a small step forward in fuel cell research, the public may also remember and wonder why the much heralded energy revolution was still in abeyance. However this game is played science does not come out at all well.

Of more significance is the fate of the inhabitants near the Northern Italian city of Seveso, where in 1976 a chemical factory blew up releasing dioxin into the surroundings. Dioxin has been claimed to be one of the most toxic chemicals around. Helen Caldicott, an Australian environmentalist, has been reported as saying that the scourge of dioxin would make AIDS pale in comparison. Fortunately for the world, the preliminary findings on the carcinogenic properties of the dioxins have not been confirmed, and it is now thought to be no more dangerous than more common chemicals such as benzene or carbon tetrachloride, or even smoking. However, prompted by the hysteria following the Seveso incident, 90 women had elective abortions for fear of abnormalities in their offspring. In 1988 a ten year study of foetal abnormalities in the region after the incident revealed no increase in abnormalities near Seveso (Mastroiacovo et al., 1988).

**The Cultural argument**

There was a time when kings of England were noted for their learning and knowledge of the world. Henry VIII was the epitome of a Renaissance monarch and would have been abreast of the latest in scientific theories. (He also would have had a court astrologer, but such were the times). Up to one hundred years ago, to be an educated person in Europe or America, required a working knowledge of science and emerging technology. In the mid nineteenth century around a dinner table in London, it was as likely to hear a debate on the latest theories of evolution of Mr Darwin, as on the scandalous paintings of the French Impressionists. The acceptance of natural philosophy as one facet of our understanding of the world was without contention. Weighty matters worthy of dispute still remain, so why is there not the popular debate about, for example, whether the emergence of life is inevitable and ubiquitous, or whether we on planet Earth are unlikely winners in a cosmic game of Lotto? Recent work on chaos, fractals and complexity lead to challenging conclusions about the

Universe, that can be understood and debated by the intelligent public. Why do people discuss their horoscopes, or indulge in pointless superstitions when the real world is so interesting and worthy of thought?

The descent of science is encapsulated in the writing, and subsequent bastardisation, of Mary Shelley's "Frankenstein or, the Modern Prometheus" (Shelley, 1817). At the time, Mary Shelley believed she was contributing to the general debate on the nature of life. In the preface to Frankenstein, she writes:

"The event on which this fiction is founded has been supposed by Dr Darwin, and some of the physiological writers of Germany, as not of impossible occurrence."

Frankenstein is no crazed and mad scientist, but a troubled, thoughtful man whose experiment has gone awry, and who has the ultimate obligation to accept responsibility. The real story is about the human condition, of what it means to be human (or simply a bunch of body parts), and of our reaction to the outsider. By the time Boris Karloff (Universal Pictures, 1931) is swanning around with a bolt through his neck, albeit with certain pathos, the message is lost, and all that remains is a confusion between the monster (unnamed) and Dr Frankenstein (the mad scientist).

The reason that Mary Shelley did believe that such events were possible is that the experiments of Dr Frankenstein had already been attempted. In 1793 F X Bichat attempted to revitalize bodies and reunited heads of guillotined aristocrats, during the Terror in France. In1803 Giovanni Aldini (a nephew of Galvani) experimented on newly hanged English murderer Forster. He subjected the corpse to 'the precise effects of galvanism with a voltaic column of one hundred and twenty copper and zinc couples' (Hibbert, 1993b). The connection between electricity and life was firmly in the public's minds.

**The Political argument**

The poor perception of science by the public feeds through to the politicians, who then react in ways that are contrary to the long term interests of society. Of great concern is the lack of understanding of risk. It has been shown that the perceived risk of living next to a chemical works is much greater than that of regularly driving a motor car, and yet, in fact, the position is reversed.

There are two local examples of the pressure exerted on politicians by public chemophobia. The first is the removal of asbestos and PCBs (polychlorinated biphenyls) from schools in New South Wales. When a fluorescent light fitting leaked PCBs the public outcry was sufficient to force the government to spend scarce health resources on replacing all such lights. In the light fitting, the PCBs were quite harmless, and a more considered, leisurely replacement scheme, while being no greater risk, would cause less disruption and would be much cheaper for the public purse. However any chemical risk is seen as unacceptable. The removal of asbestos in building materials is another debatable issue in the same vein. While in walls and ceilings the asbestos poses no risk, so when is the best time to remove it? The answer may not be 'now' while the building is in use.

In the 1980s and early 1990s there was a debate in Australia concerning the building of a high temperature incinerator to dispose of intractable wastes. The case was overwhelming, except for the fact that dioxins are produced in small quantities by the incineration of many organic compounds. Unfortunately the question of the high temperature incinerator coincided with the hysteria over dioxins and the public concern was such that the project did not go ahead. Intractable waste is now dumped in land fill with the much greater potential to be a long-term hazard for the country.

## A 'good news' story – the Cochlear Implant

The foregoing discussion leads to the conclusion that a greater level of understanding and information must be imparted to the public. The program must work at all levels, from the youngest (in schools), through the readers of the popular media to the decision making politicians and members of the business community. Thus far it appears that science has been largely reactive, with obvious apologists appearing whenever there is a problem, or a condescending style of 'look what you would be missing if we were not here' advertisement. Some years ago the Australian mining industry ran a series of advertisements on the television depicting what would be left in a typical house if the products of that industry were removed. The naked inhabitants of a hole in the ground were supposed to impress on the public the vital need for the mining and minerals processing industry to thrive. The naivety of such an approach was amazing, and I cannot believe that it did anything positive for the industry.

One approach that may fare better is to be proactive about success stories and try and display a positive attitude to science. The Cochlear implant is an Australian invention that has brought hearing to about 16,000 profoundly deaf people. The company is profitable, invests in research and can indeed be held up as 'science helping humankind'. After briefly describing the device, the foundations of this technology in science will be discussed. The Cochlear implant will also allow us to show that nothing is entirely free from contention, and that scientists must be very careful in proselytising business from which they derive research funds.

### The Cochlear implant

The Cochlear implant is a prosthetic device that stimulates the auditory nerve in

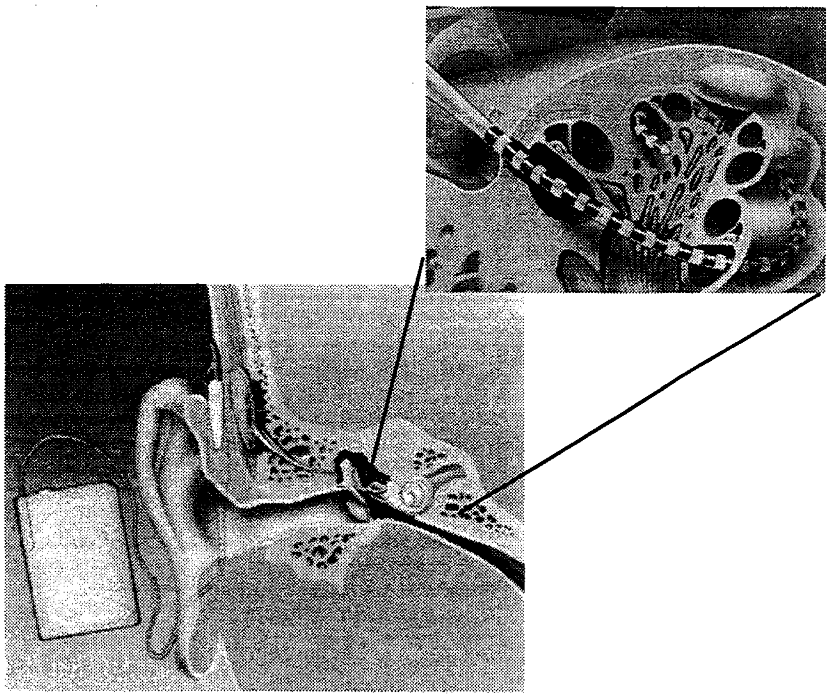


Figure 1. Schematic of the Cochlear implant. Reproduced with kind permission of Cochlear Pty Ltd.

response to sound. It is designed for the profoundly deaf following certain illnesses or accidents in which the cilia in the cochlea are destroyed. The device is surgically implanted after which the recipient undergoes an extensive training to learn to interpret the current pulses in terms of hearing. The implant, surgery and following training is expensive (around A$20,000), but may be covered by public medical benefits.
The device has two parts. Externally, sound is received by a microphone and the signal is then processed by electronics worn on a belt. The output is a radiofrequency signal that is sent through the skull behind the ear to a receiver, which responds by applying short (200 μs) current pluses between specific pairs of electrodes located in the spiral cochlea (Fig. 1). In a present design there are 22 such electrodes.
The technology has been extensively developed in recent years and the company now claims that users of the device score nearly 80% in standard hearing tests. Research is being conducted into a device that will stimulate the brain stem directly, for those whose auditory nerve is not functioning.
The company has financed research (with the Australian Government) into the electrochemistry of the device. The work provides an interesting example of how understanding the fundamental science can aid the development of the technology.

**Electrochemistry of platinum in perilymph**

The liquid inside the cochlea is known as perilymph. It is a saline solution containing amino acids and proteins. The implant operates by passing current between platinum electrodes through the perilymph, and so the research started by investigating the electrochemistry at platinum in such a solution. The composition of perilymph is known, so the experiments could be carried out *in vitro* in an artificial solution.

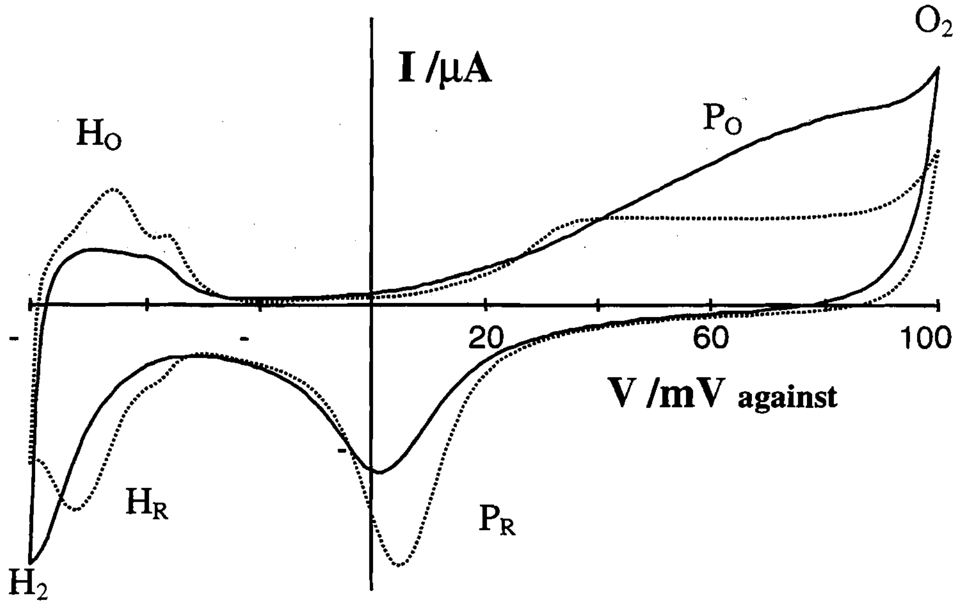



Figure 2. Cyclic voltammogram of a platinum electrode in phosphate buffered saline (dashed line), and artificial perilymph solution (solid line). See text for details.

Experimental details may be found in Weitzner (1998) and future publications of the author. Cyclic voltammetry is a technique in which the potential at an electrode is cycled linearly with time between set lower and upper limits. The measured current is

displayed against the voltage (Fig. 2) and from this it is possible to gain insights into the electrochemical mechanisms at the electrode. In phosphate buffered saline, peaks due to platinum oxidation and reduction (peaks $P_O$ and $P_R$ respectively in Fig. 2) and hydrogen ion reduction and oxidation of adsorbed hydrogen atoms ($H_R$ and $H_O$ respectively) may be seen. At the extremes of voltage, water is broken down to hydrogen gas ($H_2$) and oxygen gas ($O_2$).
The study shows that the presence of perilymph, and in particular its amino acid content, causes a depression of the platinum oxidation and reduction currents. In the anodic region, current is increased as the perilymph itself is oxidised. The hydrogen region is also affected by the adsorption of amino acids. Experiments with and without added human serum albumen, show that there is no extra effect due to protein.

**Dissolution of platinum**

A second aspect of the electrochemistry of interest to Cochlear was the extent to which platinum may dissolve during the operation of the device. Platinum is a toxic heavy metal, and although it is known to be chemically inert, long term use as an electrode does raise questions of dissolution and release of platinum into the body. From the results of our investigation it appears that the adsorption of amino acids suppresses the dissolution of platinum at the potentials of operation of the device. At more extreme potentials adsorbed compounds appear to disrupt the passivating layer of oxide and promote dissolution.

**Modelling the behaviour of the implant**

The ubiquity of modern computers has allowed development of sophisticated modelling techniques that can be used for a range of scientific and technological problems.

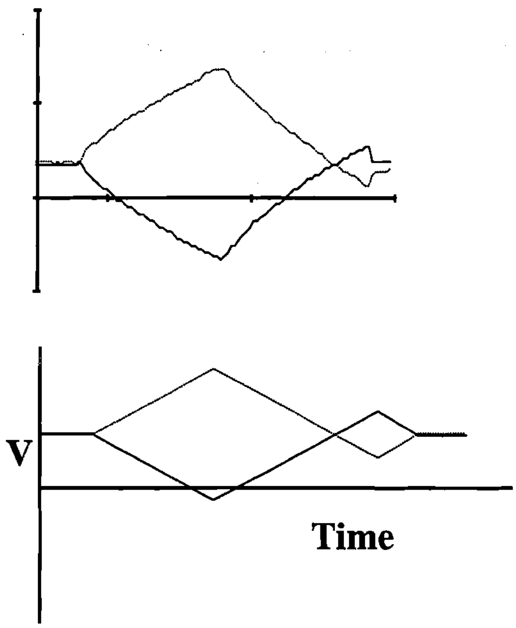



Figure 3. Upper graph: voltage response from a Cochlear array corrected for solution resistance. Lower graph: modelled voltage response assuming double layer charging only.

Simulating the response of a device can save considerable time and cost in bench experiments and, in the medical field, testing on animals or humans. A computer program was written in C++ (Borland C++ Builder V1.0) to simulate the voltage output of two electrodes given the current profile, and parameters of the different electrochemical reactions (Fig. 3). Double layer charging, platinum oxidation and reduction, and other electrochemical reactions were programmed. Using the program it is possible to determine voltage limits during operation, what electrochemistry is happening and what parameter ranges are safe.

## Joining the public debate on hearing prostheses

### Negative views on hearing prostheses

From the above discussion it would appear that the Cochlear implant is an ideal example of the benefits of scientific research. However, while the science is unarguable, the sociology of the deaf community has brought into question the use of prostheses. Oliver Sacks (1995) sums up the problem

> "But in addition to these cognitive problems there are identity problems too; in a sense they must die as deaf people to be born as hearing ones. This, potentially, is much more serious and has ramifying social and cultural implications; for deafness may not be just a personal identity, but a shared linguistic, communal, and cultural one."

In other words, is it desirable that a 100% functioning deaf person become, at great expense, a 80% hearing person? Not being deaf, I cannot answer the question easily. Proper counseling and a full understanding of the arguments is needed for a person (or parents of a deaf child) to make a decision. In addition there is the political debate as to whether the expense should be borne by the state or the individual. Should a researcher, who is a good electrochemist, buy into the argument or remain aloof, simply offering the benefit of his or her scientific knowledge?

### Funding of research

Before the previous question is addressed, a further complication arises. Should our scientist say anything at all if the research being done was funded by the company in question? There has been considerable debate about the ethics of accepting research funds from tobacco companies, and more recently from pharmaceutical companies, the adage 'he who pays the piper calls the tune' being cited more than once.

A famous historical case is that of R.A. Fisher (Gould, 1996), who, while being a paid consultant for the Tobacco Manufacturers' Standing Committee produced papers (the data for which is now found to be deeply flawed) to show that the extent of inhaling tobacco smoke does not affect the predisposition to lung cancer, and that the rate of lung cancer had increased faster in men than in women. Fisher took great umbrage at the suggestion that his objectivity may have been compromised, but, as Gould notes "Higher powers must judge the tangled commitments wrought by such employment; ...".

Merely being bought off by big business is not, I suspect, the problem. There is a more insidious pressure resulting from any relationship. I have a good working relationship with my opposite number in Cochlear, whom I respect as a fellow scientist. The financial side does not come into it, but I would still find it difficult to criticise in public any aspect of the Cochlear implant. Conversely, if the relationship had been a disaster, as occasionally happens, it may well be that spleen would cause a ready flight to the press with prejudicial stories, real or imagined.

**A scientist's duty to debate**

Final evidence for the correct approach of science to the community comes from a professor of semiotics. Umberto Eco (popularly famous for his novel The Name of the Rose) was asked by an American reporter how he reconciled his academic work with his regular contributions to a popular newspaper. He replied (Eco, 1995a)

> "This habit [of writing for the popular press] is common to all European intellectuals ... where a scholar or scientist often feels required to speak out in the papers, to comment, if only from the point of view of his own interests and special field, on events that concern all citizens."

Unlike in America where scholars are compartmentalized, it is seen as a duty of academics in Italy to enter the political arena and offer their opinions on pressing matters of the day. That all speak out does not mean that we will like or agree with everything they say. In one of his articles on a new film on China by Antonioni, Eco (1995b) writes of *medicina povera* that it

> "... substitutes the rediscovery of the relationship between human beings and medicinal herbs, and the possibility of a new, popular knowledge, for the poisoning of our pharmaceutical industries."

Professors of semiotics need education about science as much as the average person. If the debate is vigorous many strands of opinion will be given but ultimately understanding will eventuate.

## Conclusions

In this paper I have argued that the present low point of science in the eyes of the community will not be solved by naive attempts to talk down to an erring populace who only need careful guidance to see the truth and the light. Nor will it suffice to present only the 'good news' in the face of opposition, albeit from minorities. Scientists need to understand their place in the world, and interact from a knowledgable and concerned standpoint. Decisions made as a result of our work impact on us, quite as much as on the next person. Hopefully, we are at least as articulate as the average person, and so must be prepared to take a full part in the debate, accepting that there are other arguments and that our own position may be called into question.

If the community perceives scientists, not as 'old, deranged men in white coats' but as fellow members equally as concerned and committed to a better world, science may have made a start on the road to regaining credibility.

## Acknowledgments

Dr Roy Tasker of the University of Western Sydney is thanked for his statement of the three arguments for science. Ms K Weitzner (UNSW) and Dr P Carter and Mr B Tabor (Cochlear Pty Ltd) are acknowledged for their work on the electrochemistry of the Cochlear implant.

## References


Eco U. 1995a. *Faith in Fakes,* Minerva, Random House, Sydney, p vii.

Eco U. 1995b. ibid. p284.

Gimpel J. 1995. *The End of the Future – the waning of the high tech world.* Praeger Publishers, USA.

Gould S.J. 1996. *Dinosaur in a Haystack.* Jonathan Cape, London, p300.

Hibbert D. B. 1993a. *Introduction to Electrochemistry.* Macmillan Press, London, p317.

Hibbert D. B. 1993b. ibid. p255.

Hibbert D. B. 1994. 'A Chemical Free Lunch', *The Skeptic,* **14** (1), 36-37.

Mastroiacovo P., Spagnolo A., Marni A., Meazza L., Bertollini R., Segni G. and Borgna-Pignatti, C. (1988) 'Birth defects in the Seveso area after TCDD contamination', *J. Am. Medical Ass.*, **259** 1668-72.

Sacks O. 1995. *An Anthropologist on Mars,* Picador edition, Pan-Macmillan, Sydney, p135.

Shelley M. 1817, *Frankenstein or, the Modern Prometheus,* Golden Heritage Series, published by Galley Press, London, 1988.

Universal Pictures Company 1931, *Frankenstein.*

Weitzner K. (1998). *Electrochemical studies of auditory prostheses.* PhD thesis, University of New South Wales, Sydney.

# 'GET REAL' - BRIDGING THE GAP BETWEEN SECONDARY AND TERTIARY

**D Brynn Hibbert**

*School of Chemistry, University of New South Wales, Sydney, NSW 2052*

## Abstract

The three or four years that a tertiary student spends between school and the work force are typified by the change from a school student to a maturing professional. One aspect of this change is that increasingly the results and outcomes are important. A theme, therefore, in the analytical courses at the University of New South Wales (UNSW) is one of receiving marks for the actual result turned in by the student, and less for good excuses why it is wrong. To expect greater rigour from students requires a case to be made for their increased effort. The present concerns about the quality of analytical results are discussed, highlighting the conclusions from several international studies that the most important factor in achieving correct results is the quality of the analyst. Employers stress planning team work and presentation skills, often over advanced laboratory skills. Tertiary institutions are responding to this by implementing more group project work. Analytical chemistry provides an excellent vehicle for providing realistic situations for students to learn in. Examples of laboratory based projects and case studies are given.

An argument for university-like education is that research informs learning and that exposure to the cutting edge of a subject provides important benefits to students. An example of this is the development of a portable 'electronic nose' at UNSW for measuring car exhaust pollution. High profile exposure to the public was followed by its use in a third year project and then for use by students to solve a real-life problem that arose in the university.

## Introduction

A tertiary course in chemistry may be seen as a bridge between secondary school and the workplace. Starting a course at a university brings a student into contact with working chemists whose task is to not only add knowledge about the subject, but to give an awareness of what it means to be a professional chemist. The bridge that I shall discuss here therefore is concerned with that transition between bright young student and bright, young, maturing professional.

One approach is to ask employers of chemists what they value in a graduate. It has been reported in this conference that the wish list of employers has more general, personal skills than specific chemical skills (McKinnon et al., 1998). This supports much anecdotal evidence from university chemistry departments, visiting committees and RACI surveys. It is often the case that the would-be employer takes for granted the basic chemical skills, but it is important that universities heed the comments, and find sensible ways of providing what industry wants. Rather than providing separate 'problem solving skills', or 'public speaking' classes, we believe that integrating into the

chemical curriculum the need to work in groups, problem solve, or present results, is the correct approach.
This paper explores three scenarios of real world learning; giving marks for correct results, project-based subjects and using high-profile research in undergraduate courses. The 'get real' message will also be underpinned by a discussion of why 'getting real' should matter anyway, in the light of findings about the quality of analytical chemistry results.
A general tone of these innovations is embodied in the title of this paper – 'get real'. If the student can be exposed to situations that are sufficiently real world like, then pertinent skills will be learned.

## Marks for results

### The analytical quality problem

Analytical chemistry is at a critical point in its history. Used as never before in industry and commerce, hardly any goods cross a national boundary without analysis by seller and buyer, almost no trip to the doctor fails to generate a specimen for analysis, no facet of the environment now goes unsampled. Whether a direct result of this increased activity, or a parallel development to it, recent publicity has been given to claims that a significant fraction of chemical analyses are wrong. The US Food and Drug Administration (FDA) announced that one quarter of all medical pathology had to be repeated. The UK Government Analyst proposed that one third of chemical analyses were not 'fit for purpose' (Hibbert, 1997). There is discussion about how uncertainty should be treated in analytical chemistry, and even whether the term 'uncertainty', which took over from 'error', should not itself give way to 'certainty' (Sargent, 1996). Bringing this debate to the attention of students may shake their confidence in the infallibility of their mentors, but may also impress them with the need for competence when dealing with life-and-death issues.
Recent examples come from a series of studies funded by the European Union, called the International Measurement Evaluation Programme (IMEP) (van Nevel et al. 1996, 1998). The programme offers reference values, established by primary methods, against which participating labs can evaluate their performance. The degree of comparability is thus established against the most objective references available at present. Two of the rounds (IMEP3 and IMEP6) were concerned with analysing water for trace elements. Two samples were sent to each of 169 laboratories in 29 countries. The samples containing 14 elements at trace levels (0.01 – 30 $\mu$mol kg$^{-1}$) had been prepared by the National Institute of Standards and Technology (NIST) and analysed by isotope dilution mass spectrometry to an expanded uncertainty ($k = 2$) of 2%. Each laboratory was invited to return the concentration of each element in each sample, an uncertainty range, the method used, whether the laboratory considered itself experienced in this analysis, and whether the laboratory was accredited by a national body. The results showed evidence of bias, with a number of laboratories returning values up to 3 orders of magnitude away from the assigned value. There was no correlation between the ability to determine the correct answer and the method used, the experience of the laboratory, nor the level of accreditation. Many of the laboratories did not know how to express uncertainty. There was no obvious improvement between the rounds. The leader of the programme, Professor De Bièvre has come to the conclusion that the quality of

analytical results depends on but one thing – the quality of the analyst. This is a heartening conclusion for an educator.

Another example from pathology is the determination of lithium in blood. Lithium is used to treat certain types of personality disorders. It is given orally and blood samples must be analysed frequently in order to establish a correct dose for each patient. Figure 1 shows the analyses of two samples containing 19 μmol lithium in serum by six pathology laboratories. All but one laboratory obtained high results. Indeed some laboratories could not tell the difference between a therapeutic and a toxic dose. The problem with this interlaboratory comparison is that using normal statistical methods to analyse the data the only correct laboratory would have been rejected as an outlier!

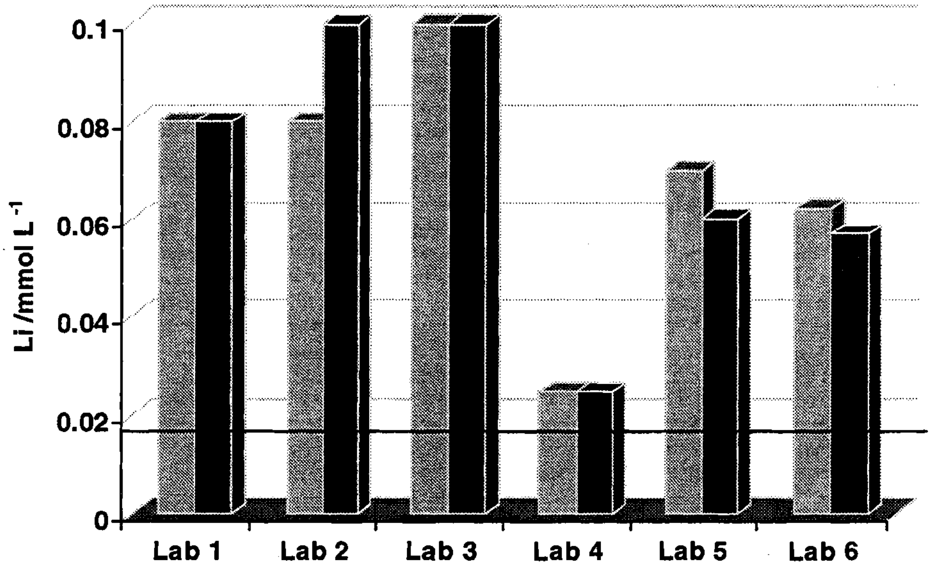



Figure 1. IMEP results for the analysis of lithium in two samples of serum. Certified value 0.019 mmol $L^{-1}$.

## The undergraduate laboratory

The community of analytical chemists has long known that they are obliged to deliver results that are 'fit for purpose', ie capable of answering the client's problem within an agreed time frame and budget. One obvious aspect of this is accuracy. Having discussed with the second year analytical class about the current concerns of the outside world, we then explain that we too will demand a high level of professionalism from them. In particular the majority of the marks for the class will be given for the correct answer (ie value plus uncertainty plus units), and that the excuse that "the method was correct, only I made a mistake in writing the answer down", will not attract much sympathy. The scenario of a hospital with grieving relatives of a patient, who was prescribed double the correct dose of a highly potent drug because the pathologist forgot a 2 in the calculation, usually suffices to concentrate the students' minds.

It must also be pointed out that the right answer is not everything. A properly kept work book and an ability to show how the answer was arrived at are also essential. In these laboratory classes the analyses are not particularly realistic, being designed to teach a given method. We believe, however, that an emphasis on obtaining a proper answer will prepare the students for the project-based subjects that they will encounter in their third year.

## Project-based undergraduate courses

### Laboratory projects

Project-based, group practicals are an excellent way of addressing the concerns of employers that students do not have enough group skills such as problem solving in teams and presenting work to others. While many departments have introduced this into final year subjects, the School of Applied Chemistry of Curtin University of Technology has demonstrated that such classes may also fit into second year curricula (Dunn and Phillips, 1998). The argument against this approach is that time that would have been spent rehearsing and learning basic chemical techniques is given over to the more general personal skills, and that there is a danger of turning out good problem solvers who are not equipped with basic knowledge about chemistry to solve anything. However, the message from employers is clear, these skills are essential and they are lacking in the majority of chemistry graduates.

Figure 2 shows a typical brief given to two or three third year students who have chosen the analytical chemistry elective. The ten weeks of the project, which takes place in the four hour laboratory slot for that subject, is broken up into four weeks preparation, four weeks experimental work and two to finish off and write up. At the end of the preparation phase the group gives a presentation to the class, outlining the problem and the approaches they mean to use to solve it. In the final week, they give a second presentation with the results and conclusions. The long preparation time gives the students an opportunity to understand the client's problem, search the library and Internet, discuss with people in the School (who may be senior technicians - a good source of help), and try out the technique if they are not familiar with it. The presentations are encouraged to be as professional as possible, using PowerPoint on

**Lead Pollution in the University Environment**
**Aim and Background**

UNSW is in a densely populated area, with high traffic volumes especially on weekdays. Lead pollution associated with car exhaust emissions may be a potential health hazard for staff and students. However, there has also been a move to unleaded fuel in recent years. So how significant is lead pollution around UNSW? You are called in as the consultants to provide a report to the university community on this issue.

**Specialised resources available for this project**
**(in addition to the general laboratory facilities)**
Techniques for lead analysis (ASV, AAS, ICP)

**Member of Staff for Consultation : Dr Moran**

Figure 2: Brief for a third year analytical project on lead in soil.

overheads or computers. In 1998 we propose to ask some groups to give a presentation to a non-chemist client, who must be persuaded that the problem is in good hands even if she cannot understand all of the jargon. We also may arrange a courtroom drama, in which some of our Science–Law students will test the students' ability to defend their work in a hostile environment.

### Case studies

Outside the laboratory, there is opportunity to give instruction through the contemplation of realistic scenarios. In an environmental subject, a number of case studies are worked through with the students, from the point of view of the analyst who is called upon to set up a program, or to determine the effect on the environment of chemical pollution. An example popular with the students is the collision of two ships in the Mississippi River Gulf Outlet in 1980, releasing an interesting cocktail of pentachlorophenol, hydrobromic acid, vinyl polymer and ethyl mercaptan into the waterway (DeLeon et al., 1982). Each day the waterway was closed cost of half a million dollars, there were important oyster beds in the delta and New Orleans was nearby. Therefore there was a need for rapid and accurate analysis to establish the extent of the pollution and the efficiency of the clean up. As well as the obvious analytical aspects of sampling, the analysis of the target compounds in water, sediment and biological samples, problems such as capacity of the laboratory, maintenance of quality control and health and safety of personnel are also discussed. The problem allows the lecturer to introduce information piecemeal (as, of course, happens in practice) which requires the students to estimate when they do not have full knowledge. "How much PCP is likely to have been released?" "What concentrations should we be looking for in the water?" are questions that arise early in the discussion.
Everyone is relieved to discover that only PCP was released in significant amount and that caused little damage to the environment. Of interest is that the species analysed as having accumulated the greatest amounts of PCP during the spill were humans taking part in the clean up operation.

## Research to Learning

An excellent way of enthusing students and giving them experience is to use the results of research in the undergraduate program. We were fortunate in having a project, the electronic nose, that had attracted some high profile media coverage, was straightforward to explain in chemical terms, and could be used by the students within the constraints of an undergraduate practical.

### An electronic nose

Electronic nose technology embodies the concept of multiple, non-selective sensors giving signals that may be calibrated for a given range of gases (Gardner and Bartlett, 1994). As its name suggests the idea is to ape the mammalian olfactory apparatus (the nose). A human nose has several million receptor cells with a few thousand different types, capable of distinguishing between about ten thousand odours. Present electronic devices are more modest in their complexity, having two to thirty sensors programmed for fewer than a dozen gases. The neural network processor of a mammal (the brain) also has the edge on the algorithms used by computers to unscramble the signals coming from the sensing device (Hibbert, 1998).

Many different types of sensor are known, but the most popular is the Taguchi sensor based on a thin film of semiconducting tin oxide. Vapours that adsorb on the surface and can react with oxygen change the resistivity of the film. By doping, some partial selectivity may be imparted to the sensor.
UNSW developed two and three-sensor devices that were calibrated for petrol vapour (as an equivalent concentration of butane) and carbon monoxide, both pollutants associated with automobile pollution. The portable device was used to check the exhausts of individual cars, and also as a mobile pollution monitor for measuring general levels in the air (Fig 3).

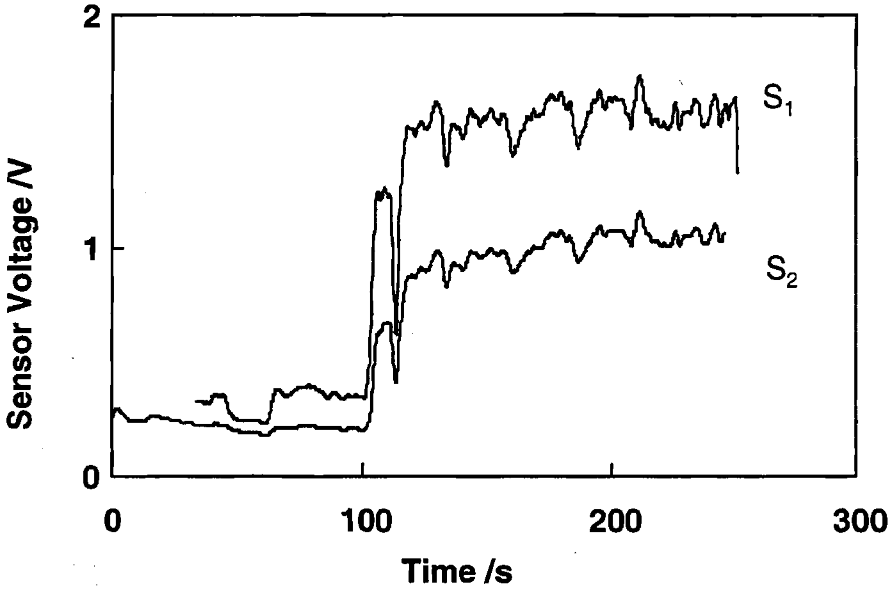



Figure 3. Output of two Taguchi sensors exposed to the exhaust from a Holden Commodore.

**Air pollution in Sydney**

Although air pollution in cities around the world is generally less than a decade ago, following the introduction of catalytic converters, and more efficient engines, air quality is still a matter of major public concern.
When the Sydney Harbour tunnel was opened in September 1992, we were invited to monitor the tunnel using our portable analyser. On the day the tunnel opened we went through it with a TV crew and pronounced the air in the tunnel "better than in the Central Business District". Another TV station had picked up the story, and two days later we found ourselves driving through the tunnel with our device monitoring the air. This time we met a wall of white fumes and the sensors' responses showed a great increase (Fig. 4). There had been a minor problem with the settings of the ventilation, which was quickly fixed, but the incident caused a certain amount of public interest. Newspapers took up the story with headlines such as "Tunnel trapping danger gases" (Daily Telegraph Mirror, 3/9/1992), and "Uni sensor sniffs out air culprits" (The Australian, 5/9/1992).
It is possible to build on this incident, using the media reports of the time to discuss questions like, "What is the air quality in Sydney?", "How do we measure it?", "What do we measure?", "How should the results be communicated to the public?".

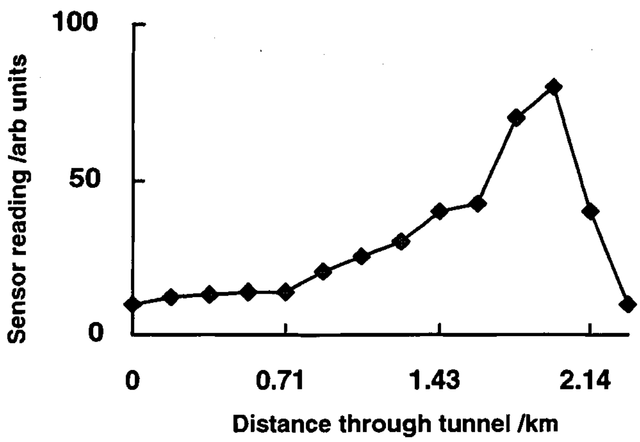



Figure 4. Sensor reading during trip through Sydney Harbour Tunnel, September 2nd 1992.

**A third year project**

One of the prototype sensors was given over to a third year analytical class and formed the basis of a practical experiment. The students are asked to go out onto the main road that passes the University (Anzac Parade) and measure levels of hydrocarbons and carbon monoxide near flowing traffic, at some pedestrian traffic lights, and on the median strip. A mobile telephone can send the results back to the School by FAX. The instrument is sensitive enough to pick up the exhaust signature from individual cars and trucks, and it is possible to build up enough information for the students to start a discussion on the nature of automobile pollution.
As this device is a real research instrument, the undergraduates tend to interact with postgraduate students, and they gain some insight into the nature of research.

**Pollution in the university?**

The involvement of undergraduate students gained a boost in 1996 when the University moved its main vehicle entrance a few hundred meters up Barker Street, and re-established it opposite a child care centre. At peak times cars queuing to enter the University (particularly those turning right) were providing a source of automobile exhaust gases close to where kindergarten children were playing. Worried parents approached us to determine if the levels in the child care centre were in any way dangerous. Two students spent a summer vacation project making measurements. They discovered the problems of sampling and calibration, and of what to do in the vacation when the volume of traffic was considerably less than in term time. The results suggested that there was no evidence, from this study, that the levels of hydrocarbons and carbon monoxide were in at all dangerous. Both students decided to stay in the School and take honours.

## Conclusions

It is possible to find many instances in which the philosophy of 'get real' can be applied in an undergraduate chemistry degree. From the earliest times it can be impressed on them that results do matter, and that their progress will be measured in terms of the correct answers. In the real world there is little room for a good effort, but the wrong result. Project work, with groups of students being set realistic tasks, should be introduced as soon as possible. Here the level of realism is only limited by the imagination of the academic. Aspects of funding and cost may be introduced, the 'clients' may suddenly change their mind *in medias res*, and the students may have to defend their results in a 'court of law'. Institutions with a thriving research culture can draw on that experience to provide interesting and pedagogically-sound examples to feed down to the undergraduate curriculum.

One of the more important aspects of 'get real', is that the academics themselves have to be convinced that the examples are indeed realistic and worth taking seriously. Once enthused, the students do strive to do a professional job, and, hopefully, carry on this philosophy to their employment when they leave the protective confines of university.

## Acknowledgments

The third year analytical project laboratory in the University of New South Wales was conceived and is implemented by Dr G. Moran.

The electronic nose and pollution monitor was developed with Professor P.W. Alexander now retired from the University of Tasmania, Launceston.

## References

DeLeon I.R., Overton E.B. and Laseter J.L. (1982). *The role of analytical chemistry in a toxic substance spill into the aquatic environment*, in Analytical Techniques in Environmental Chemistry 2. Ed J.Albaiges, Pergamon Press, Oxford, 1–18.

Dunn J.G. and Phillips D.N. (1998). Introducing second-year chemistry students to research work through mini-projects, *J. Chem. Ed.* **75**, 866–869.

Gardner J. W. and Bartlett P. N. (1994). A brief history of electronic noses, *Sens. Actuators B*, **18**, 211 – 220.

Hibbert D. B. (1997). *Quality and Integrity of Data*, Proceedings 14th Australian Symposium on Analytical Chemistry, Adelaide July 1997, ed S. McLeod, Analytical Chemistry Division, Royal Australian Chemical Institute, Melbourne, ISBN 0 909589 93 3, pp 7 – 10.

Hibbert D. B. (1998), *Data analysis of Array Sensors*, ARC Special Initiatives Program. Workshop on Electrochemically Based Microsensing Arrays, University of Wollongong, February 1998, ed G Wallace, Univ. Wollongong, ISBN 0-86418-487-5.

McKinon I.R., Nunn, E.K. and Patti A.F. (1998), *What laboratory related skills do employers want from chemistry graduates?*, Bridging the Gap, eds D. Druskovich and G. Klease, Central Queensland University.

van Nevel L., Taylor P.D.P., Örnemark U. and De Bièvre P. (1996). *International Measurement Evaluation Programme (IMEP) - 6: Trace elements in water. Report to Particpants*, European Commission, Brussels.

van Nevel L., Taylor P.D.P., Örnemark U., Moody J.R., Heumann K.G. and De Bièvre P. (1998). The International Measurement Evaluation Programme (IMEP) IMEP-6: "Trace elements in water". *Acred. Qula. Assur.* **3** 56–68.

Sargent M. (1996). Confidence in Analysis. *VAM Bulletin (Autumn 1996)* pp 3-4.

# EXTENDING THE RANGE OF TEACHING APPLICATIONS FOR THE IEC* STUDENT SPECTROMETER

**R J Hodges and H Pillekers**
*Monash University, Gippsland Campus, Churchill 3842*

**Abstract** In the last 40 years, chemical analysis has increasingly moved from "wet-way" methods to instrumental techniques giving greater detail about samples in shorter periods of time. Comprehensive elemental analysis generally no longer needs chemical separation steps, but the sample as a whole when excited in a flame or plasma gives spectral lines for all elements present. However molecular analysis of mixtures still involves separation, since broadening by vibration and rotation fine structure give overlapping spectra that prevent accurate interpretation. Chromatography is frequently used for separation. "Wet-way" group precipitation and separation methods once prepared secondary school students well for industrial analysis but to ensure the present generation is adequately prepared for the 21st century, low cost teaching equipment that relates to modern practice is needed. This paper outlines an earlier teaching spectrometer development extended to flow injection analysis (FIA) and gas chromatography (GC).

**Introduction** The year 12 chemistry program for the Victorian Certificate of Education includes a major section early in the year (unit 3) relating to modern instrumentation. Students have a work requirement involving some "hands-on" experience with at least one technique, and to achieve this many schools organise a field trip to a local university or industrial laboratory. When first implemented these were run on a goodwill basis, however they soon became too large an exercise for most establishments to conduct free-of-charge. At Monash, for both the Gippsland and Clayton campuses, students are charged a nominal fee (typically $10-12) for the half day exercise which involves about 1,000 students. This is run over about one week just before the University semester starts. Goodwill at industrial laboratories is harder to maintain on an ongoing basis, thus for students in regional centres not serviced by tertiary education establishments, the need for suitable equipment at the school itself is highlighted. Some schools already have the IEC spectrometer (about 120 units have been sold) and we have noticed that local students who have already used that equipment do gain a lot more when on the field trip as they are well prepared for and easily relate to the more sophisticated equipment.

A three way spectrometer (see Figure 1, made by IEC Pty Ltd) for teaching visible absorption, flame emission and atomic absorption was developed, marketed and demonstrated earlier (Hodges, 1992). The equipment also gives stable flame colours as an alternative to elementary tests (McKelvy, 1998). Photographic filters (Fifield and Kealey, 1995) were used for the monochromator and medical aspirators for sample introduction into the flame to keep costs to less than A$1500. Output was linked to IBM compatible computers in keeping with modern spectrometer practice.

FIA is important as it allows rapid "on-line" analysis of specific components for routine quality control work. The IEC spectrometer together with the computer readout and data storage facility has proved ideal for extending to FIA teaching applications by

* Industrial Equipment and Control P/L, Thornbury, Vic

merely adding a flow cell. A simple flow system (Greenway and Harris, 1996) uses gravity and a plastic syringe to inject the sample.

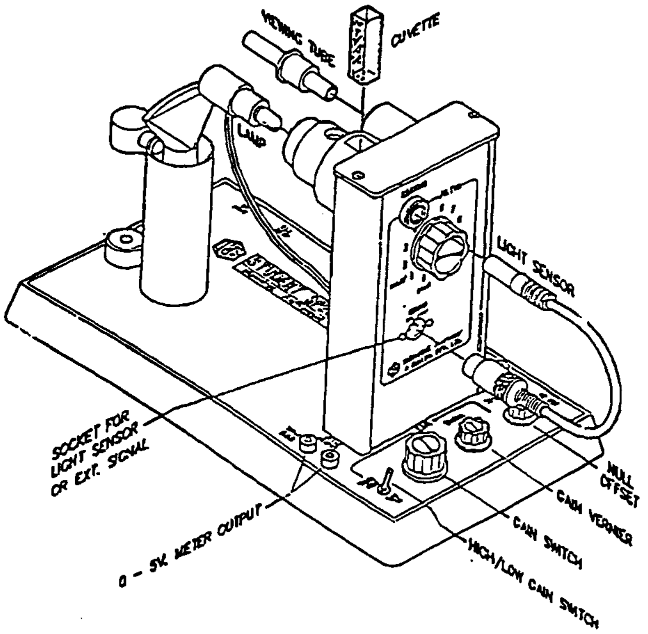



**Figure 1:** Student Spectrometer designed for colorimetric, atomic emission and atomic absorption spectroscopy (produced by IEC, Thornbury Victoria).

To teach chromatography, attachments have been made to extend the existing hardware. The spectrometer was originally designed to take an external signal from an analogue output like a Carle GC, which used a thermal conductivity detector and a Wheatstone bridge circuit. However this approach needed compressed helium gas (expensive) as the mobile phase for adequate sensitivity and the cost of even this simple GC was more than the spectrometer. The more sensitive flame ionisation GC detector needs hydrogen as the mobile phase and special high tension circuits.

A low cost attachment and circuit was needed to plug into the sensor port, capable of separating mixtures and detecting simple compounds. For teaching, in a limited time frame, temperature programming limits throughput. Ideally room temperature isothermal work gives minimal delay. A very low cost and easiest-to-obtain mobile phase is air, thus a hot wire sensor for hydrocarbons was selected (RS Components, 1991), which uses catalytic oxidation and ohmic resistance for the signal.

Soap powder as a low cost stationary phase illustrated GC for chlorinated hydrocarbons using a green copper flame (Bricker *et al*, 1981) and more recently, a HP 5890 chromatograph gave better chromatograms (Furton and Mantilla, 1991).

A third area of ongoing development uses sensors like selective ion electrodes and one of the most important of these is the pH electrode. The authors developed a variation of the spectrometer A-D circuit using only the power (3 mA) already available from the serial port of the computer and separate software to display output from emf sources.

**Special Apparatus** The circuit used for producing the auxiliary GC input signal using the Pellister effect detector is shown (Figure 2) which plugs into the sensor port of the spectrometer (Figure 1).

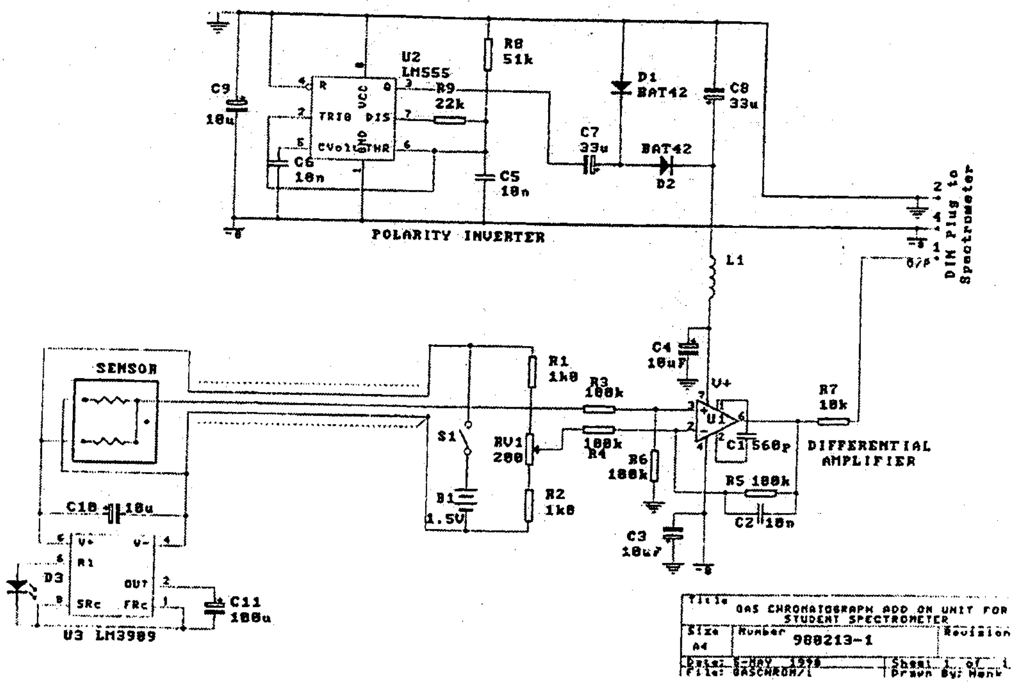



**Figure 2:** Circuit used to plug into the sensor port of the Student Spectrometer and detect flammable organic vapours

**Results** *Flow Injection analysis.* Results obtained with a simple gravity feed flow injection system for iron using thiocyanate (a basic reaction taught both in UK and Victorian courses) are given (Figure 3) and a peristaltic pump for phosphorus by the molybdenum blue method, are shown (Figure 4).

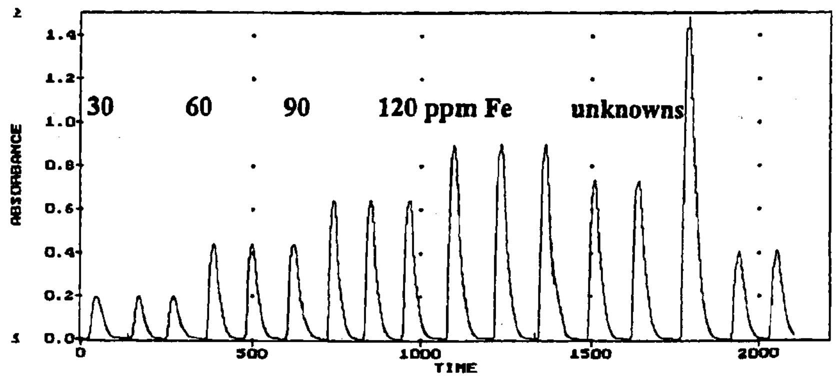



**Figure 3:** Flow injection trace for the analysis of iron (III) by the thiocyanate reaction using the Student Spectrometer, a flow cell with gravity feed.

*Gas Chromatography* Despite the fact the spectrometer already had a suitable flame, we found the use of chlorinated hydrocarbons too restrictive as only halogenated alkanes were suitable and the green copper flame too insensitive for quantitative work. Further, studies using soap powder as the stationary phase also showed two problems when used for teaching:

(i) Whilst finely screened soap powder gave acceptable separation when first placed in a column, after a period of time voids between the particles were lost. This caused excessive back pressure and loss of flow of the mobile phase. New columns require too much effort for setting up.

(ii) Larger particles of soap powder did permit adequate low pressure flow using inexpensive pumps (like fish tank air pumps) but the porous nature of the particles gave excessive tailing due to diffusion into, and out of the stationary phase.

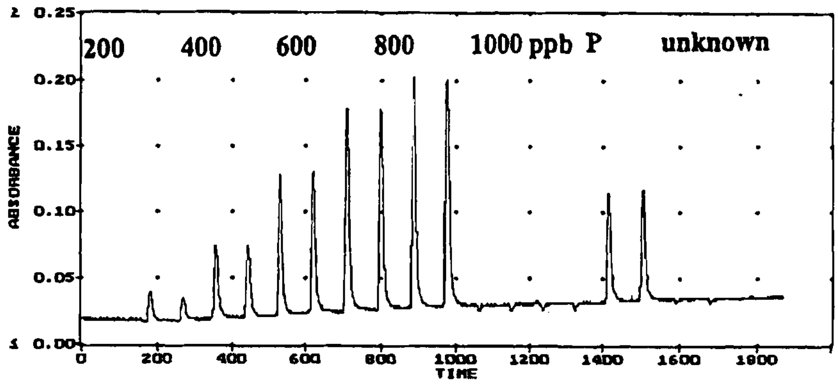



**Figure 4:** Flow injection trace produced by students for the analysis of phosphorus using the Molybdenum blue method and peristaltic pump.

For the work described here, we used glass beads (60 mesh) which were packed dry into a 2 meter long 6.5 mm ID teflon tube which was then coated with a dilute solution of paraffin oil in n-pentane. The excess solvent was evaporated off overnight using a fish tank air pump. This stationary phase gave enough voids for a flow of 20 to 50 mL per minute. The very thin active stationary phase did not give significant tailing for simple volatile hydrocarbons like butanes, pentanes and hexanes. A typical GC is shown (Figure 5).

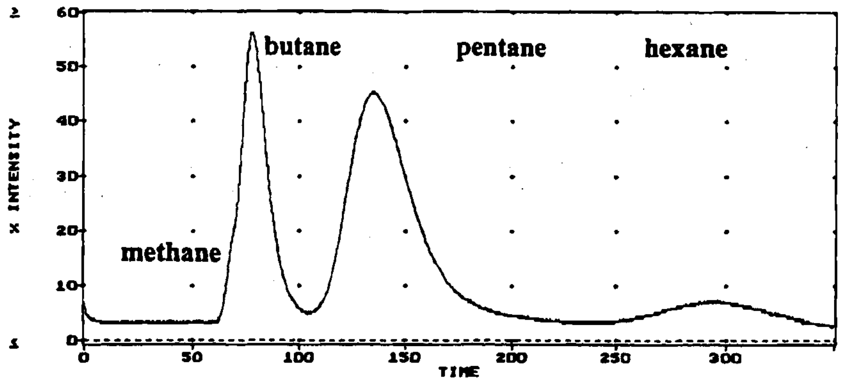



**Figure 5:** Separation of volatile alkanes using a 2 meter column packed with glass beads (60mesh) coated with paraffin oil using a one mL plastic syringe to inject vapour and a fish tank air pump for the mobile phase flow.

*pH measurements* The interface for pH and other electrodes to the computer bypasses the spectrometer altogether, but uses the same 8 byte AD converter chip and very high input impedance components so that the pH electrode gives a suitable emf response. One feature of this direct interface is the dual input or differential "Instrumentation Amplifier" arrangement which had the added advantage of making the interface behave as a 9-bit AD converter with a resolving power of 1 in 512 possible on the screen. A pH titration curve for this system and software is shown (Figure 6).

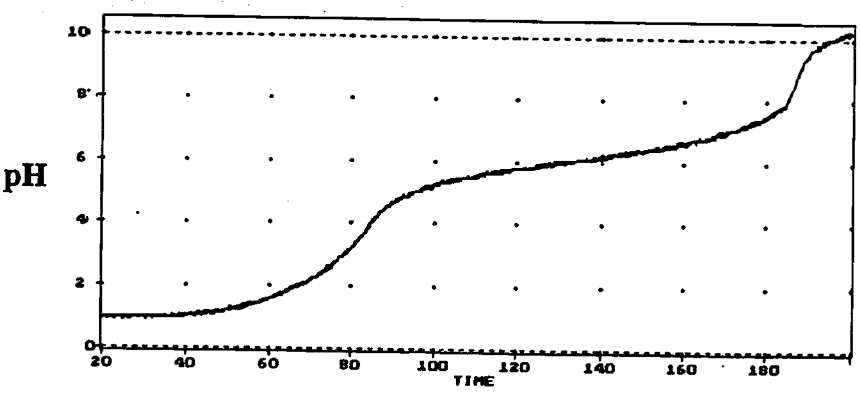



**Figure 6:** pH titration response of phosphoric acid using the "Instrumentation Amplifier" powered by the serial port of the computer (3mA). O.1M NaOH was added at 10 mLs per minute.

**Discussion and Conclusions** The spectrometer already sold in the IEC package adequately covers the teaching needs in elemental analysis, but not the growing need for species and/or molecular analysis such as chromatography nor the trend towards automated analysis. Advances in instrumental techniques are particularly relevant to this country since Australians, Sir Alan Walsh (1991) and Ian McWilliam (see Willis, 1992) respectively, developed atomic absorption and the flame ionisation detector for gas chromatography.

The extensions illustrated above, namely (i) flow injection analysis (simulating on-line single species automated analysis), (ii) gas chromatography, showing how mixtures of compounds are separated by fluid flow and (iii) selective ion electrodes (eg pH) do permit the IEC equipment to introduce these key areas of modern instrumental analysis.

During the coming year, the authors have offered a number of summer scholarships for students from year 12 students to test and evaluate new experiments and the equipment prior to the next update of the manual and hardware.

**References**

Bricker C. E., Taylor M. A., & Kolb K. E., 1981, *J. Chem. Ed.*, **58(1)**, 41

Fifield F.W. & Kealey D., 1995, "Principles and Practice of Analytical Chemistry", 4th Ed., Chapman and Hall (Blackie, Glasgow), p 275

Furton K. G. & Mantilla A., 1991, *J. Chem. Ed.*, **68(1)**, 74-77

Greenway G. M., & Harris S., 1996, *RCS Ed. In Chem.*, **33(3)**, 73-4

Hodges R. J., 1992, RACI 9NC (Chem Ed Div) Melbourne Dec 6-11, 18-25

Hodges R. J. & Hodson B. L., 1992, *Internat. Chem Ed. Conf. (12 ICCE, Bangkok)*, Dec 17-21, 173

Hodges R. J., 1995, *Lab Talk, J Sci Teachers' Assoc Vic.*, **39(1)**, 18-22

McKelvy G. M., 1998, *J Chem. Ed.*, **75(1)**, 55-6

RS Components Ltd., 1991, Handling Manual M728 286-614, 13pp

Walsh A., 1991, *Anal. Chem.*, **63(19)**, 933-41A

Willis J., 1992, *Chem. In Aust.*, **59(5)**, 206-8.

# CHEMISTRY PROBLEM SOLVING AND REAL WORLD KNOWLEDGE

**R. W. Hollingworth**

*Division of Chemistry, University of New England, Armidale, NSW, 2351*

**Abstract**

Our surveys of students entering first year chemistry show that their knowledge of scientific facts in the real world is quite limited and often inaccurate. All teachers can recall many instances of students giving wildly implausible answers to chemistry problems, indicating they have very little understanding of the physical significance of their answers. We have made a start to developing students' metacognitive skills in chemistry problem solving in two ways. First, by assisting them to specifically consider the sizes of objects in the real world, to build up a reliable mental database of scientific facts about the real world and to relate this to quantities in chemistry problems. Second, to check on the physical significance of their problem answers by checking against this background knowledge. This is being done in part by an on-line quiz, where feedback to the students plays an important part in showing how to build up a real world knowledge base and how to relate chemistry problems to this.

**Introduction**

We all have examples in our teaching, of students giving obviously implausible answers to chemical problems or not understanding the physical significance of what they are doing in practical work. I give a couple of recent examples from my own experience.

1. A chemistry problem asked students to calculate the increase in their body temperature after eating a bowl of cereal, given the calorific value of the cereal. For an average student mass, the temperature rise is about 0.3 °C. One student calculated a rise of over 100 °C, a disastrous result for all those regularly eating a bowl of morning cereal!
2. Students were asked to prepare an ice-water slurry to cool a reaction mixture in a laboratory experiment. One pair gave the temperature as -5 °C; and when asked if they thought this unusual, they replied this was what the thermometer read. When asked the freezing point of water they immediately replied 0 °C. These students had felt no inclination to query their result for the temperature of the slurry.

Clearly students do often have the background knowledge to realize that their answers are unreasonable, since this can easily be elicited with a little questioning. They also have the knowledge to assist them in their tasks in the laboratory, but often are not in the habit of questioning themselves to call upon this information. We all encourage our students to check their answers when doing chemical problems. "All teachers know that good students check their work. Teachers also know that admonitions to do so fall on deaf ears. Research on problem solving also reveals that successful problem solvers spontaneously engage in many strategies that effectively verify that procedures and conclusions are logically sound and accurately executed." (Herron 1996, p73) The many schema in the literature for problem solving all include a check on the answer. (For example, Polya, 1957, Bransford and Stein, 1993, Woodcock, 1995.)

With this background, we decided to carry out a survey to determine more accurately students' estimates of the sizes of some common quantities. We wanted a measure of our students' state of knowledge and were looking for sensible estimates, rather than strictly accurate ones. If students do not even have reasonably accurate ideas about common objects, then they can hardly be expected to have any feel for the reasonableness of the less familiar quantities they encounter in chemical problems. To further address this need we are now developing an on-line tutorial introducing students to common physical quantities, units, etc. In this tutorial most emphasis is placed on the reasons why the answers to the simple quizzes are what they are.

**Results and Discussion**

***Survey:*** We surveyed 159 students entering first year chemistry. These were in two major groups; the first group of 111 were internal students, a fairly homogeneous group of mainly recent school leavers, who were less than 25 years of age. The second group of 48 contained external students, who came from much more diverse backgrounds and many of whom, were mature adult learners. The students were asked to give the magnitude and units for the sizes of 30 common physical and chemical quantities. The questions were arranged into several groups as listed in Table 1, where some of the results are summarised.

Some questions gave a little more detail than is listed in the table, so that the required quantity was clear to the students. The table shows the number of responses for which we could list a quantifiable answer. Responses were converted to a standard unit convenient for each question. In some cases students gave no units, but the meaning was obvious. In other cases no units or very odd units were given and no intelligible answer could be deduced from the written answer. Where a range was given we used the average. We calculated the average, median and mode for the responses to each question and these are given in the table with the minimum and maximum answers. Due to considerations of brevity we can only make a few comments about some specific questions here.

*Lengths:* Most students were able to give reasonable answers for the height and width of the sheet of A4 paper, the dimensions of a 20 cent coin and their own height (nearly all gave a very specific measurement). More difficult were thickness of paper and the length of forearm (even though it was right there in front of them) and it was rather surprising to find a student with a forearm thought to be 1m long! There were 138 responses for the diameter of a human hair. These are shown in Figure 2, with a spread over several orders of magnitude, indicating very poor estimating skills for this quantity. Diameter of a copper atom ranged from $10^{-27}$ to $10^{37}$ nm, the exponents obviously causing great trouble. Out of 72 responses for the wavelength of red light 41 were between 600 and 800 nm. Exponents again caused great trouble.

*Masses:* Masses were more difficult. The mass of the A4 paper is rather deceptive and a wide range of answers was given. A histogram of responses is shown in Figure 1. Mass of the coin was poorly estimated. Mass of a teaspoon of sugar ranges from 0.01 g to 100g, but most were a more reasonable few grams. Results are shown in Figure 3. For the mass of 2l container with milk, 23 out of 139 responses were less then 2 kg and the average was 1.95 kg! The mass of air in their bedroom presented a real challenge, with responses spread fairly evenly from 0.1 to 50 kg, with a slight peak at 5-10 kg. (The actual mass in a room of size 4mx4mx3m is about 56 kg.) We feel answers such as 0.1 g or 3000kg are not sensible.

*Temperatures:* Normal human body temperature was one of the most accurately known quantities. This must be a figure strongly placed in most students' minds. The temperature of a refrigerator was well known, but the temperature of a hot drink had widespread answers mainly from 40 - 100 °C. (100 °C is not a sensible answer.) Room temperature was correct to within a couple of degrees. There were only 87 responses for the temperature of dry ice, ranging from –300 °C with a peak of 33 responses in the 0-25 °C range and 2 responses higher than that. The histogram for melting point of sodium chloride is shown in Figure 4. There were 28 responses out of 82 less than or equal to 100 °C indicating perhaps confusion between melting and dissolving.

*Chemical Composition:* Students were asked what metals are in a 20 cent coin. A very wide range of metals was mentioned for the composition. In fact the coin is made from cupro-nickel alloy containing 75% copper and 25% nickel. There are also very small quantities of manganese, zinc and tin of the order of 0.1 – 0.2%. The number of times different metals were mentioned by students were: Nickel 65, Silver 49, Copper 32, Aluminium 29, Tin 28, Iron 20, Zinc 16 and Lead 4. The word "alloy" was mentioned 15 times and there were a few other odd combinations.

*Other:* The volume of a can of Coca-Cola was the best-known quantity, presumably because most students drink this and have seen the volume on the label. There were only a few wrong answers, perhaps confused with other sized cans or bottles. Estimates of the volume of a cup of tea were spread from 100 – 300 ml, with a peak at 250 ml.

Only half or less students answered the last group of questions. It is distressing to note that 39 out of 85 responses for the atmospheric pressure gave an answer equivalent to 1 atmosphere, even though the students were in Armidale at an elevation of ~1000m.

| Q No | Quantity | No of Responses | Actual Value | Average | Median | Mode | Minimum | Maximum |
|---|---|---|---|---|---|---|---|---|
| | **The survey sheet of paper** | | | | | | | |
| 1 | Height / cm | 153 | 29.7 | 31.5 | 30 | 30 | 24 | 100 |
| 2 | Width / cm | 154 | 21.0 | 20.2 | 20 | 20 | 40 | 60 |
| 3 | Thickness / mm | 148 | 0.1 | 0.25 | 0.10 | 0.10 | 1.00E-09 | 5.0 |
| 4 | Mass / g | 143 | 5.0 | 1.84 | 0.80 | 1 | 1.00E-07 | 25 |
| | **20 cent coin** | | | | | | | |
| 5 | Diameter / mm | 156 | 28 | 26.9 | 25 | 25 | 3.0 | 120 |
| 6 | Thickness / mm | 154 | 2 | 2.96 | 2.5 | 3 | 3.00E-06 | 35 |
| 7 | Mass / g | 128 | 11.3 | 11.7 | 10 | 20 | 7.00E-04 | 100 |
| | **Your own body** | | | | | | | |
| 10 | Length of your forearm / cm | 154 | 27-33 | 33.7 | 30 | 30 | 20 | 100 |
| 12 | Diameter of hair on head /mm | 138 | ~0.075 | 0.13 | 0.05 | 0.10 | 1.00E-13 | 1.00 |
| | **Drinks** | | | | | | | |
| 13 | Volume of a can of Coke / ml | 154 | 375 | 8802 | 375 | 375 | 7 | 1.00E+06 |
| 14 | Temperature of can of Coke taken from refrigerator / °C | 153 | 3-5 | 5.3 | 4 | 4 | -5 | 20 |
| 15 | Vol of a cup of tea / ml | 147 | 180 - 230 | 224 | 250 | 250 | 5 | 1000 |
| 16 | Temp of cup of hot tea / °C | 152 | 60 – 80 | 72 | 78 | 80 | 1 | 100 |
| 17 | Mass of 1 teaspn of sugar / g | 137 | 3 – 6 | 8.6 | 5 | 5 | 0.01 | 100 |
| 18 | Density of Coke / g $ml^{-1}$ | 62 | 1.03 | 1.45 | 1.01 | 1.00 | 1.05E-03 | 20 |
| 19 | Mass of 2 l plastic bottle containing milk / kg | 139 | 2.1 | 1.95 | 2.00 | 2.00 | 0.1 | 4.5 |
| | **Other** | | | | | | | |
| 25 | Atm press in room / mm Hg | 85 | 680 | 5926. | 760 | 760 | 448 | 3.42E+05 |
| 26 | Diameter of a Cu atom / nm | 81 | 0.25 | 1.23E+35 | 1.36E-01 | 1.00E+00 | 1.00E-27 | 1.00E+37 |
| 27 | Heat of fusion of ice / kJ $mol^{-1}$ | 17 | 6.0 | 2700. | 2.26 | 1.00E-03 | 1.00E-03 | 4.50E+04 |
| 28 | Temperature of dry ice, / °C | 87 | -78 | -67 | -30 | -20 | -300 | 45 |
| 29 | Melting point of NaCl, / °C | 82 | 801 | 460 | 215 | 200 | -30 | 3500 |
| 30 | Wavelength of red light / nm | 72 | 650 - 750 | 6.26E+12 | 655 | 700 | 1 | 4.50E+14 |

**Table 1. Survey on Sizes of Quantities**

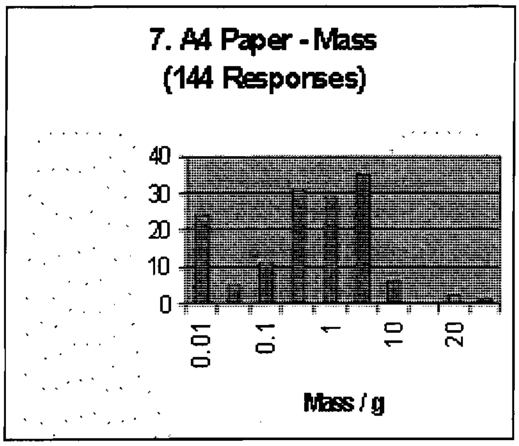



Figure 1 Mass of A4 Paper

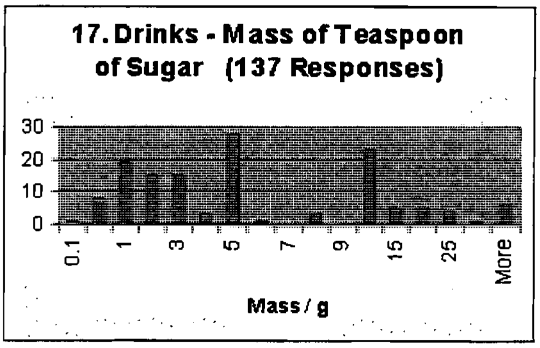



Figure 3 Mass of a Teaspoon of Sugar

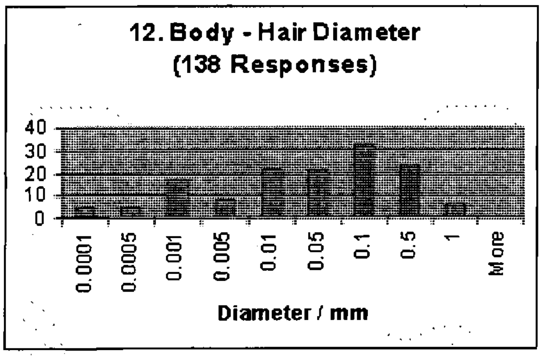



Figure 2 Diameter of Human Hair

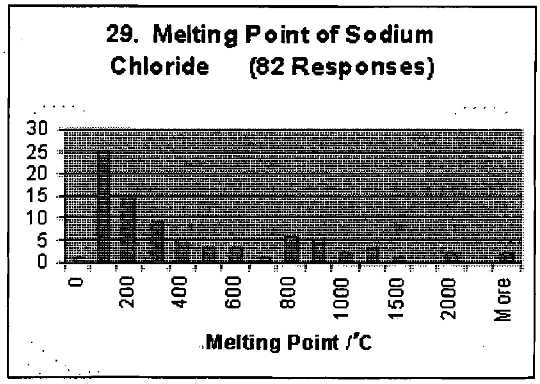



Figure 4 Melting Point of Sodium Chloride

Students' conceptions of nature move through a sequence of epistemological perspectives or *positions* according to Perry (1970). Many of our students appear to be still at the stage of Perry's *basic dualism,* where as passive learners, they are dependent on authority to hand down the truth and tell them what is right or wrong. A later stage is *relativism subordinate*, where an analytical and evaluative approach to knowledge is consciously and actively cultivated.

We feel that the results of the survey indicate that we need to place much more emphasis on developing students' ability to relate chemistry to the real world. They must be able to make connections from chemical quantities to familiar objects as a first step, before they will be able to make sense of less familiar quantities often involving very small or very large numbers. An analytical and evaluative approach needs to be more explicitly nurtured. (Zadnik and Loss, 1995; Sleet et al, 1996) Research indicates that developing metacognitive skills for problem solving will be more effective than spending more time on mere practice at chemical problem solving. (Herron, 1996 and references therein, p85.)

***On-line Tutorial:*** In order to assist our students strengthen their metacognitive skills in problem solving we are now developing an on-line tutorial in WebCT, called "Making Sense of Your Answer." The tutorial comprises several modules, each with a short multiple choice quiz at the end. The modules cover: Sizes of familiar things, The SI system of measurement, Comparative sizes of objects, Conversion between units, Estimating answers in calculations, Some real problems.

We have taken considerable time to give sufficient explanation to all answers in the multiple choice quizzes, to enable students to see some of the ways of thinking about answers and checking on their reasonableness. WebCT is a full system for developing courses on-line and we have taken advantage of this to use the bulletin board feature to obtain feedback from students. Encouraging a habit of reflection on their problem solving is important. Their comments are helping us to develop the tutorial and to build up a resource bank on problem solving and checking answers.

## Conclusion

Our survey results tend to confirm both science teachers' intuitions and research into metacognition. It seems possible, even probable, that unless we take explicit steps to help learners to move beyond *basic dualism* they will not reach the analytical / evaluative stage, let alone eventually become "passionate knowers," that is constuctivists who enter into a union with what is to be known. (Belenky et al, 1997, p141) Our initiative with the on-line tutorial should indicate the feasibility of assisting these changes.

## References

Belenky, M. F., Clinchy, B. M., Goldberger, N. R. & Tarule, J. M. (1997) *Women's Ways of Knowing,* Basic Books, New York.
Bransford, J. D. & Stein, B. S. (1993) *The Ideal Problem Solver, Second Ed,* W. H. Freeman & Co, New York.
Herron, J. D. (1996) *The Chemistry Classroom, Formulas for Successful Teaching,* American Chemical Society, Washington.
Perry, W. G. (1970) *Forms of Intellectual and Ethical Development in College Years,* Holt, Rinehart & Winston, New York.
Polya, G. (1957) *How to Solve It,* Doubleday Anchor, Garden City, N.Y.
Woodcock, D. (1995) Problem Solving in Chemistry, The A thru E Approach.:
URL http://oksw01.okanagan.bc.ca/ chem/probsol/ps_A-E.html
Zadnik, M. G. & Loss, R. D. (1995) Developing numerical problem solving skills through estimations of quantities in familiar contexts, *Aust Sci Teachers J,* 41, 15.
Sleet, R., Hager, P., Logan, P. & Hooper, M. (1996) *Broader Skill Requirements of Science Graduates,* University of Technology, Sydney.

# CHEMISTRY 123: A FOUNDATION LEVEL COURSE FOR EXTERNAL STUDENTS

**R. W. Hollingworth**

*Division of Chemistry, University of New England, Armidale, NSW, 2351*

**Abstract**

Students come to study first year chemistry at university, but unfortunately too many of them are ill prepared to do so. The is true for school leavers, but also more frequently for distance education students, who come from a very wide variety of backgrounds and periods of time since last studying any chemistry. This paper outlines the features of a one semester foundation level chemistry unit, offered by distance education, to bridge the gap between the students' existing chemical knowledge and that required as a prerequisite for entering first year chemistry. Mention is made of a range of media and teaching/learning strategies used to build an interesting and relevant chemistry unit at this level.

**Introduction**

For many years we have faced the problems of students entering first year chemistry without an adequate background at final year high school level. This can be a very negative experience both for the students and for the staff teaching them. Previously we offered a very short bridging course of one week's duration, but clearly such a short course cannot possibly cover two years' work. Due to the obvious need for a proper preparatory course and because we have been enrolling increasing numbers of external students, who have long periods since they last studied chemistry, we introduced Chemistry 123 in 1996.

This is a one semester external unit offered in the second semester of the academic year. Since it was so successful in its first year of operation, we decided to also offer it over the summer semester, that is December and January, to allow further students to complete it in time to enter first year chemistry in the following year. Similar offerings were made again in 1997 and we are now about to accept our third intake in second semester 1998. Numbers enrolling in the unit so far have been around 130 and 30 for the second and summer semester offerings respectively each year.

The unit does not involve any compulsory residential school or practical work (except for a few simple experiments carried out at home.) The textbooks for the unit are "Introductory Chemistry" (Zumdahl, 1996) and "SI Chemical Data" (Aylward and Findlay, 1994). Students are supplied with a whole range of learning materials and support, which are described in detail below. Assessment is by three submitted assignments and one examination at the end of the semester. Student response to the unit has been very positive, as noted below.

**Discussion**

In designing this unit three important aims were to:

- Provide as wide a range of learning materials as reasonably possible within the constraints of cost to the university and to students
- Provide a range of learning activities
- Present the students with relevant and challenging problems

Because different students have their own preferences for different modes of learning, we wanted to provide a range of learning materials and activities for them. All students are presented with the basic materials of textbooks and workbooks on which the unit is based plus one video and five audiocassettes. Depending on the facilities available to the particular student, additional materials can supplement the above. We have not just concentrated on high tech materials, but included audio and video tapes, which virtually everyone has facilities for using. Our surveys show that about 80% of students have access to a computer and about 25-30% have access to email and the Internet. (This number is growing at a very rapid rate.) We felt we must provide materials and facilities that these students could use to maximise their learning opportunities. Also we wished to develop our own experience with new materials and technology, so we too can keep abreast of latest developments.

*Learning Materials*

Like many modern chemistry **textbooks**, Zumdahl has clearly stated learning objectives at the beginning of each section, contains clearly worked examples, provides self test examples for students and Chemistry in Focus sections. At the end of each chapter are key terms, summary and additional problems. We felt that the presentation was very clear and our students have particularly remarked on this. Rather than repeat material covered so well in the text, we built a student workbook to complement it.

The **workbook** guides the student through the sections of the text, suggesting what to read, when to do particular exercises and when to use the other audiovisual materials we supply in the learning materials. There are chapter pre-tests and guides to what must be known before starting on each chapter. Also given are, extra information on common misconceptions for many topics, points at which to use audio or videotapes, other learning activities, simple experiments to perform, as well as end of chapter review activities. Thus, as they work through the unit, students are very clearly guided as to what to do, but it is their choice as to how closely they wish to follow the workbooks. (Students come to the unit with a wide range of experience and some appreciate more guidance than others.)

Emphasis throughout is given to ensuring students understand concepts. End-of-chapter summaries assist them to be clear on new terminology and help them concentrate on tying concepts together by assisting them to construct concept maps. After completing the chapter or module, students should be ready to tackle the assignment problems. (These are discussed in more detail later in this paper.)

We have produced a number of **audiovisual materials** to assist students. **Audiotapes** include "Introduction to the Unit," "Study Tips," "How to Use Your SI Data Book" and "Questions and Answers About...". "Introduction to the Unit" is aimed at welcoming the students and informing them of various administrative matters. We feel it is important to give students assistance with regard to study skills, particularly in relation to studying chemistry. "Study Tips" is a general talk about effective study, but emphasises concept maps particularly. "How to Use Your SI Data Book" is an activity tied in with the workbook, searching for data. In our experience many students use data books very ineffectively. This cassette aims to introduce and explain all the tables in the SI Data Book, then asks students to search for specific information and finally gives answers and comments on this. We hope that after doing the exercise they will definitely have a better idea of what data actually is in the book, but also use a more thorough approach to searching for information in books in the future.

We also produced a number of short 15 minute interviews with lecturing staff called "Questions and Answers About..." These cover the topics of Atomic Theory and Bonding, Gases, Liquids and Solids, and Equilibrium. Rather than one person giving a mini lecture, we felt it would be more interesting to hear a couple of staff discussing these topics together.

We have also produced a 30-minute **video**, "Introduction to Chemical Equations," linked to three chapters of the text. The video concentrates on the fundamentals of balancing and classifying chemical equations. The workbooks note clearly when to view sections of the tape. Students see equations and reactions mentioned in the text. Quite a lot of graphics animation was used since much of the material is rather abstract.

We spent considerable time searching the Internet for free **computer software**, which was relevant for our students. If students indicate to us that they have access to a computer, they are given two floppy disks of programs. The most important is RasMol, the molecular viewing program, made available freely on the Internet by Roger Sayle. (Sayle, 1994; Martz & Finlayson, 1995) Students are also given a number of molecular files so they can view various simple molecules and ions, they come across in the unit. Other programs include a chemical calculator and unit converter, "Science and Pseudoscience," "Stoichiometry Tutorial" and a chemistry game.

Producing media materials is a very time consuming and costly enterprise and we have only done this for areas in which we can see a specific need and where other commercial materials were not available. Fortunately there is a wide range of material available for chemistry and we have built a small **multimedia library** for our students to borrow from. This includes audio and video cassettes, CD ROMs and computer software. Most of the items are held in multiple copies and students may borrow these essentially for the price of postage to them.

We have also built a **web site** for our external students. (Hollingworth, 1997) These pages give general information about Chemistry 123, as well as other external units. Information includes: staff teaching the unit, syllabus, latest administrative news concerning the unit and a list of useful links for chemistry students. One of the biggest problems for beginning students using the Internet is finding useful information and deciding what is relevant and reliable. We spent a great deal of time finding links to sites, which would be of direct benefit to our students. Sites include some covering study skills and problems solving, scientific magazines and journals online, periodic table, interesting molecules, and media – radio and television.

*Learning Activities and Problems*

The range of learning materials mentioned above provides a good variety of modes of learning for our students. Throughout the workbooks, active learning tasks are outlined for students to attempt. Using CD ROMs from the multimedia library or computer software adds another dimension to active learning. We emphasise making charts, summaries and concept maps.

Only a small number of **home experiments** have so far been included in the workbook. It has been difficult to find many experiments, which are absolutely safe to carry out in the home and not requiring special equipment or chemicals. This is an area we would like to develop further.

Realistically, we know students' attention will be directed towards assignment problems. We have tried to make these as relevant and as challenging as possible, given the level of the students. Many problems address objects and issues students come across in everyday life. Students need to obtain information from labels on various products, comments on the chemistry in short articles such appear in *New Scientist* or excerpts from popular science books.

*Assessment*

Assessment for the unit consists of three assignments and one 3-hour examination at the end of the semester. Assignments contain 50 multiple-choice questions and 11 problems requiring extended answers. The last problem is a longer, more challenging problem for which students can receive bonus marks. For assessment we have paid particular attention to devising relevant problems, designed to test students' understanding of concepts.

*Student Support*

We strongly encourage our students to keep in contact with us by whatever means they can. Staff are freely accessible individually by **telephone, fax or email.** Also we set up an **email listserver** to encourage students to discuss issues with each other and with staff. About 25-30% of our students have access to email and the Internet at present. This means only a relatively small number of students can participate in this activity. It is an area we would like to improve, as we have found it rather difficult to encourage these students, who after all are beginning science students, to discuss issues openly with others.

Students also have access to a **Voicemail** service. This is apart from the private voicemail individual staff have. By dialing the number after hours, students may access three boxes. The first is for short current administrative messages and replies to their queries. The second is for longer messages from staff, including general comments on performance in assignments and explanations of some minor topics. These messages are refreshed on a regular basis. A third box is available for students to leave their messages.

Students may submit their **assignments by email**, but very few have done so to this stage. Producing documents containing chemical equations, symbols and molecular diagrams is quite a time consuming task for anyone who is not very proficient or had considerable experience at using word processors.

A significant number of our students actually live in Armidale and some are doing other subjects internally. As a result we have provided **tutorials** in Armidale for these students in the weeks before each assignment is due. Students living away can ring us on a special phone-in night in these weeks also.

We run an **optional weekend school** about a third of the way into the unit. It is designed to let students interact with staff, clear up problems, gain a little practical experience and view a range of the multimedia materials in our library. This school was made optional since it involves a significant cost for some students far away to come to Armidale for such a short time. Some students are keen to get some practical experience and the school can help to allay a lot of fears about studying chemistry.

A **regular newsletter** is sent to students, usually with the return of their assignments. This includes latest news of an administrative nature as well as worked assignment answers and general comments on assignments

Our latest endeavour is to build an **on-line tutorial** in WebCT. This tutorial is titled, “Making Sense of Your Answer.” It contains a number of modules including, "Sizes of Familiar Things," "SI System of Measurement," "Unit Conversions," "Estimating Answers," and "Real Problems." The tutorial commences with a discussion of problem solving in chemistry in general. Each module ends with a short multiple choice quiz. Emphasis is placed on explaining in detail each possible answer of the multiple choice questions and illustrating how to use "real world" knowledge to make sense of the answers. Tied to this tutorial is a bulletin board for students to discuss issues concerning problem solving in chemistry. We expect this to build into a useful resource for students in Chemistry 123 and our other first year units over time.

*Student Response to the Unit*
We have conducted a survey of the unit each time it has been run. The survey is quite detailed with about 50 questions covering every aspect of the unit including details of the workbooks, textbook, audiovisual materials and multimedia library. We cannot give full details of the quantitative scores on questions here, but in general the unit received very favorable response from students. Some comments are: "Find myself thinking in a whole new way. Chemistry has added a whole new dimension to my life." "I found this course challenging and at times exhilarating." "Overall well planned, well run, well supported." "I enjoyed the course and was surprised that I found it so interesting." "The Chemistry 123 unit has engendered a sea change in my attitude to the subject... I now look forward to Chemistry 101 with a sense of excitement and wonder... These changes in my attitude are solely attributable to the fine organisation and content of the Chemistry 123 unit, the excellent choice of text and the helpful, friendly and enthusiastic attitude conveyed by the chemistry department."

The university runs independent surveys of units, which have also indicated high satisfaction with the unit. The questions in these surveys are more general in nature and are scored on a rating scale of 1 to 6 ranging from strong disagreement to strong agreement. All questions had a median of 5 or 6. The lowest average of 4.48 was for the statement, "The workload expected in this unit was reasonable." Some encouraging average scores were - "The aims and assessment requirements of this unit were clearly set out," 5.68; "This unit stimulated my interest in the subject area," 5.12; and "I found this unit to be intellectually satisfying," 5.42.

**Resources**

Aylward, G. and Findlay, T. (1994) *SI Chemical Data, (Third edition),* John Wiley & Sons, Brisbane.
Hollingworth, R. W. (1997) *External Chemistry Home Pages,* URL:http://www.une.edu.au/~chemistry/external_chem/ External_Chem_Units.html
Martz, E. and Finlayson, C. F. (1995) *RasMol Home Page,* URL:http://www.umass.edu/microbio/rasmol/
Sayle, R. (1994) RasMol URL: http://www.bio.cam.ac.uk/doc/rasmol.html
Zumdahl, S. S. (1996) *Introductory Chemistry, (Third edition),* D. C. Heath & Co, Massachusetts.

# TAKING THE INITIATIVE – MAKING THE TIME – FOR SCIENCE

Roslyn Howse

*Environmental Scientist, 24 Douglas Avenue, Gladstone, QLD 4680*

**Abstract**

So, you're a scientist. When was the last time you told anyone what you do in your job? Scientists from Gladstone Industry took the initiative and went to the schools to find out how they could encourage science in schools and show what fun it was. They also wanted to explain to students and teachers the work of scientists in the industries. This group of scientists and teachers are now well know in Gladstone as the Schools and Industries Science Group.

Another group of environmental scientists from Gladstone Industry together with Government representatives created the Port Curtis Catchment Working Group. This group was successful in gaining Natural Heritage Trust funding and now employs a Waterwatch Officer and a Coastcare Coordinator. When was the last time you saw primary school children using pH meters and performing macrobenthic studies? The kids love it and so do the adults if someone takes the time to show them.

The Gladstone Regional Environmental Forum had a rocky beginning with community representatives hoping that industry representatives would join them in the formation of a pressure group. Eventually the group settled to provide an environmental forum where, for example, representatives from potential and new industries could explain processes and potential environmental impacts and questions were encouraged.

If you want to get out there amongst the community, and you are not quite sure how to go about it, come along and find out how we do it in Gladstone.

**Introduction**

Gladstone is that dirty grubby industrial city, just like Newcastle, right! Wrong! Gladstone has suffered from an image problem and it is time to get the story right. Craig Wotton a Science Teacher at Gladstone State High School described Gladstone as follows:

| | |
|---|---|
| Diversity | • A range of both large and small industries utilising both high and low technologies. |
| Vigour | • A can-do attitude that hasn't yet found the bounds. |
| Workforce | • Highly qualified specialists in a number of fields and many professionals in classic scientific disciplines. |
| Industry | • With a sensitivity to the community and a willingness to release staff during school hours. |
| Community | • With an interest in the future which it insists is balanced against social, environmental and compatibility considerations, but which is also more supportive of industry than some other communities appear to be. |

If you don't believe us take a look at what we do in Gladstone!

**Gladstone Schools and Industry Science Group (SISG)**

The group was started in November 1991 by a chemist, Trevor Davies, and an engineer Malcolm Leinster, using Malcolm's lounge room as the venue for the first meeting. Initial development of the group involved discussion by industry representatives with teachers to determine the best way to support teachers in promoting science in schools. The message from teachers was, please no more or competitions or colouring contests, and what you do must fit in with the set curriculum. Teaching units were developed for presentation by industry representatives on topics such as "Thick and Thin Liquids" and "Solids, Liquids and Gases" aimed at primary schools. Units developed for presentation at High School level include "Acids and Bases", "Environmental Monitoring" and "Oscillating and Time Clock Reactions".

When presenting sessions in the schools the industry representatives appear in normal work cloths and spend a little time talking about the job they do and the industry they work for. Presenters are careful not to give the message:

> "I am a scientist (engineer) and
> I am great and
> you should do science (engineering) and
> be like me!".

In order to work towards achieving a quality science education for all students the Gladstone Schools and Industry Science Group has worked with the following goals:

- Improve the image of science in the school community
- Promote the message: "Science is Fun"
- Promote the message: "Science is for Girls and Boys"
- Improve liaison between schools and industries in the Gladstone region
- Improve awareness of the contribution science and industry make to the quality of life.

Extended learning programs are also offered for Year 10 and Year 11 students. The Year 10 program is conducted over two days at the Gladstone Power Station. Students investigate solar collectors, pH of substances and novel applications of mathematics.

The extended learning program offered to Year 11 students is conducted over a 3 day period. The students are given a choice of topics including Forensic Chemistry, Materials Engineering, and Mangroves. At least one formal lecture on science related topics is scheduled for each day but as with all SISG programs the goal is to ensure the students have fun learning about science. The students are encouraged to complete a feedback questionnaire and the programs are modified to help ensure continual improvement. Funding is raised by letter requests to the local industries to cover the cost of providing lunches, T-shirts and consumable items. The finale of the 3 day program is a formal presentation by the students of the findings of their investigations to a group including parents, sponsors and fellow students.

**Port Curtis Catchment Working Group (PCCWG)**

The PCCWG was initiated following a workshop on the 15 July 1992 attended by representatives of the Departments of Primary Industries, Education and Environment. The PCCWG consists of representatives from Government Departments and environmnetal representatives from most Gladstone industries. It meets regularly throughout the year to provide support for the Waterwatch Officer and Coastcare Co-ordinator. In addition to financial support for the purchase of water monitoring equipment for example, the industry representatives offer encouragement and technical support (and Tim Tams). The part time salaries of the Waterwatch Officer and Coastcare Co-ordinator are paid from the National Heritage Trust (NHT) via an annual application.

The Waterwatch Officer enthused 2240 students in 1997. The Year 7 program involves 3 to 5 weekly sessions based on the theme "Everything we do is reflected in the water". Parameters students typically monitor in their local streams include turbidity, pH, conductivity and dissolved oxygen. Macrobenthic sampling stimulates enthusiasm and simple identification cards assist students to determine stream condition, on the basis of the range of creepy crawlies present. A student colouring competition was used to construct a calendar poster for 1998 and this inspired unprecedented support from the Mayor of the Gladstone City Council.

Waterwatch activities in the Gladstone/Calliope Region have largely been targeted to schools, however community programs include an annual Catchment Crawl during Water Week.

The aims of Waterwatch Queensland are to:

- Raise community awareness and understanding of water quality issues and relationship to whole catchment health
- Encourage and support participation by schools, land users, community groups, industry, local authorities and government to identify and resolve water related catchment issues
- Encourage informed community action to protect and enhance the quality of water systems and their catchments
- Provide school learning opportunities within a wide range of curriculum areas
- Provide a network to share water quality and related information and data

The Coastcare Co-ordinator commenced in April 1998 with NHT funding for the rehabilitation of Welby Creek, an alienated creek in the middle of Gladstone City. The project involves physical re-contouring, mangrove planting, water and mud analysis, macrobenthic investigation and identification of stormwater flows into the creek.

**Gladstone Regional Environmental Forum (GREF)**

Formation of GREF was initiated by environmental activists within the community in 1996. Other than the few dedicated activists the group has not yet enjoyed wider community support. Industry has found that the monthly forum is very convenient for presenting current issues and actively supports the group. Invitations are faxed to 24 organisations and individuals and attendance numbers are rarely below 20. The Gladstone City Council provides the venue and general organisation.

Topics presented by industry and Government representatives throughout the last year have included:

"Gladstone Port Authority's 50 Year Strategic Plan"
"What is happening with Environmental Education in our Schools"
"Air Monitoring in Gladstone"
"The Developing Centre for Environmental Management at CQU (Gladstone)"
"Draft Impact Assessment Study – Nickel/Cobalt Processing Plant"

Encouraging broader community involvement has been a challenge GREF would like to solve.

**Science Boxes – for Schools <u>and</u> Community**

There are a variety of science boxes available. The first science box developed by the Institution of Chemical Engineers and contains equipment for over a dozen simple science experiments, designed for use in lower primary schools. Last year Orica distributed hundreds of "CHEM" boxes to primary schools throughout Australia. "CHEM" is acronym for Chemicals, Health, Environment and Me. Importantly the "CHEM" box is accompanied by a great manual providing step by step guidance for the presentation of the 10 units including "Everyday Chemicals", "The Inside Story", "My Sweet Tooth" and "What is a Threshold"? Primary school teachers still need encouragement and support to gain confidence with the box.

If the thought of presenting to kids scares you, how about encouraging the teachers – everyone should know at least one teacher? The "CHEM" box can be obtained from the Science Teachers' Association of QLD for $250, but look around first as there is probably one nearby gathering dust. I believe the "CHEM" box has unrealised potential in the general public arena – how about the next Rotary meeting?

**Take the Initiative – Find A Way**

It is sometimes difficult to find a way to start. If you have kids or know a school teacher or a scout leader you have the perfect excuse. Double Helix offers good support with great ideas. Buy a copy of Ben Selinger's book "Chemistry in the Market Place" so you can explain everyday ordinary chemistry in everyday ordinary language. Explore the internet for ideas. Become informed about local issues and don't just dismiss the local greenie group, they might appreciate your informed comment.

So get out there and get involved. Dispel the weirdo, remote and arrogant image scientists have acquired. I continue to be surprised at the personal rewards.

**Contacts**

"*Chem Box*" is available from the Science Teachers Association Queensland Office, Reply Raid 560, School of Mathematics, Science and Technology, Queensland University of Technology, Locked Bag #2, Red Hill Qld 4059.

Waterwatch contact person is Lynne Turner, Department of Natural Resources, Resource Sciences Centre, Block A, 80 Meiers Rd, Indooroopilly, Qld 4068. (Telephone 07 3896 9737, Facsimile 07 3896 9625, E-mail Lynne.Turner@dnr.qld.gov.au)

"*Science Boxes*" is available from the Institution of Chemical Engineers.

# VIRTUAL SCIENCE FACULTIES: CONSIDERATIONS FOR EFFECTIVE IMPLEMENTATION

**Trish Andrews and Greg Klease**

*Central Queensland University Rockhampton Q 4702*

## Abstract

Virtual faculties are becoming a more common form of delivering education to dispersed students. These faculties can be inter-university as in distributed campus institutions or intra-university. They are generally built as Web based or videoconferenced environments.

This paper discusses the outcomes of several projects at Central Queensland University (CQU) involving the development of virtual science faculties using videoconferencing. These projects have involved both inter and intra-university activities. An essential part of developing such faculties is obtaining staff and student feedback about their learning experiences in videoconferenced classes. This includes addressing the issues raised by all participants and incorporating suggestions into subsequent classes.

The projects are briefly described, followed by a discussion of students perceptions and expectations of teaching and learning within virtual faculties using videoconferencing. The discussion will consider such issues as effective teaching and learning pedagogies for videoconference classes, technological issues, differences in students backgrounds and experiences, creation of a cohesive learning environment and the perceived need for staff and student preparation for these environments. The paper concludes with some recommendations for creating effective virtual faculties using videoconferencing.

## Introduction

Multi-campus institutions require the use of innovative teaching/learning and delivery strategies to provide an equitable education for all their students, irrespective of location. It is generally too expensive and not cost effective for multi-campus Universities to have all expertise located at all campuses. Additionally, students undertaking final year, honours or postgraduate courses in small regional Universities are frequently disadvantaged because of the limited specialist expertise that may be located within such institutions. The wide scale adoption of telecommunications technologies, such as videoconferencing, across Australian Universities, offers a viable avenue for linking together distributed and isolated groups of students to form "Virtual Faculties".

Collaboration between Universities and campuses could also be considered as the only means of offering some courses in specialised areas where numbers are too small in one University or campus to make the offer of such a course viable. Consequently, this type of collaboration involving small groups of students, both inter and intra-university, geographically dispersed, but sharing similar interests, enables peer collaboration and interaction that is not otherwise available. This ability to interact with peers in discussion and problem solving activities provides for a wealth of learning experiences.

CQU has funded several projects which have had the development of virtual faculties as a central focus. Two of these projects have specifically concentrated on developments in the teaching and learning of Science using videoconferencing as the medium of delivery across CQU's Central Queensland campuses. The first project sought to develop an interactive teaching and learning environment, ultimately using group based tutorials as a vehicle for creating interaction between staff and students and across sites. The second project was developed around the concept of group presentations and resource based teaching and learning. There was considerable learning by all involved in these projects concerning the necessary elements for the development of effective, interactive virtual faculty environments, highlighting the strengths and weaknesses of both these approaches. The University has also been involved in a CUTSD (Committee for University Teaching and Staff Development) project which has looked at the creation of a virtual faculty involving a number of regional Universities. Again, experiences gained from this has provided essential information as to what does and doesn't contribute to effective virtual faculties. Staff and student feedback has been an important source of information both in the development process and in evaluating the overall success of such activities.

## Description of Projects

### Interactive Chemistry Project

The Interactive Chemistry Project was an initial attempt by the Science faculty at CQU to develop an interactive model for the teaching and learning of Chemistry using videoconferencing. The project intended to involve all staff (lecturer and tutors on other campuses) in delivering the content and to foster discussion between students and staff. Training in the use of videoconferencing for both students and tutors was a critical focus of the project. The professional development activity for tutors was intended to assist them in broadening both their teaching skills and their understanding of the subject being taught. The training for students aimed to assist them in coming to grips with the technology, that is, the physical technology and communicating within the constraints of the technology, as well as working in group situations, new experiences for many students.

The project was piloted using the physical chemistry component of 83100 Chemistry 1, a large science unit for first year students and took place in first semester 1996. All students studying Chemistry 1 at the Mackay, Bundaberg, and Rockhampton campuses participated in the project, were encouraged to engage in interactive activities and were required to prepare materials or questions for the class at specified times. When students worked together in groups, the support of the other group members was useful in increasing confidence in both delivering the presentation and in dealing with questions. A successful outcome of this project was the development of an interactive tutorial approach to teaching and learning in the area of Chemistry, which encouraged active participation across all sites.

### Environmental Science Project

The Environmental Science Project aimed to introduce an innovative model of teaching and learning into the Environmental Science B unit, a second semester, first year unit. It was intended to introduce a student centred, group based teaching and learning model to replace the traditional teacher centred lecture model. This model involved the use of a range of educational technologies including videoconferencing, email and the Web. Students were required to work collaboratively in groups to address and discuss the issues outlined in resources made available to them. Engaging the students by applying content to relevant and current issues promoted discussion and argument both within and between the groups. This group learning process, using a problem based learning methodology, encouraged the development of desirable life long learning skills including information literacy skills.

Students worked in small groups both to cover content and to complete assessment requirements which formed an integral part of the activities. These aims were achieved by students sharing their information across all sites in the form of group presentations. This integrated approach to teaching and learning also included innovative assessment strategies of which peer assessment formed a part. Discussion and sharing of ideas and information was encouraged through the use of a Web page and discussion list. The Web page enabled a central point of contact for all students and lecturers across all campuses and provided direct links to a range of current resources. In order to assist students with this different model of teaching and learning, student preparation activities were an important component of this project.

### Inter - University CUTSD project

Using Chemistry as a test vehicle, the CUTSD project aimed to examine the role of inter-University collaborative teaching via videoconferencing. By means of a "Virtual Faculty" senior Chemistry students in small science departments at regional Universities were able to access classes offered by experts at distant centres. This exposure to a range of experts encouraged not only cross fertilisation of ideas between lecturers and students but also broadened isolated students exposure to a range of expert knowledge. The use of videoconferencing in this context promoted opportunities for peer and collaborative learning and thus provided richer learning environments for small groups of geographically dispersed students.

This project was seen as a crucial test of inter-university cooperation and a key option in enabling smaller Universities to maintain vigorous, high quality degree programs in the face of competing demands on finances in a climate of increasing budgetary constraints.

## Exploring Effective Pedagogies for Videoconference Classes

Student feedback from the projects outlined above, indicates that the traditional lecture, ie transmitting content knowledge, is the least preferred method of teaching using videoconferencing. This feedback is also supported by research (eg, Schiller & Mitchell, 1993). Staff involved in the projects that have been run at CQU in developing pedagogies for the teaching and learning of Science using videoconferencing have also recognised this and this realisation has encouraged them to find more interactive ways of teaching and learning that engage the learner at all sites.

The initial science videoconference project run at CQU, involving teaching undergraduate chemistry simultaneously at three sites, attempted to develop an interactive teaching and learning model involving staff and students at all these locations. Inspite of good intentions to develop a fully interactive teaching and learning model, initial attempts tended towards a lecture model based on content delivery by direct transmission, with an expectation of spontaneous interaction from students as requested by the lecturer. Feedback from students indicated this model was unsuccessful. While students could see opportunities for interaction, most felt inhibited in interacting spontaneously in front of the cameras and while open to view from a largely unknown and unseen audience (Klease, Andrews & Druskovich, 1996; Commeaux, 1995). Students also commented on a lack of content knowledge as another reason for inhibiting their participation in this environment.

This feedback along with input from the team members of the project encouraged the group to modify the approach and to develop an interactive tutorial model. It was felt that structured activity might provide an environment where students could focus on the learning, resulting in the technology becoming transparent. That is, the focus is on the teaching and learning activites rather than on the technology. Students were organised into groups and had tasks they needed to prepare for presentation to and discussion with the whole group. Some training was provided for students to assist with this process.

The other student groups in the class also had responsibility to become familiar with the content. Students commented that this approach made them come to grips with the content they had to present. They felt they really had to understand the problems and issues so they could "teach" their peers and engage in meaningful discussion. This approach considerably lessened students feelings of inhibition in communicating across sites using videoconferencing. The focus shifted to the teaching and learning activities and the technology became "transparent". Along with this change in methodology, active operation of the equipment by the students allowed them to become more familiar and comfortable with the technology, and thus feel less concerned about its presence.

Student feedback and the experiences gained from this project were major influencing factors in the design of the subsequent project, involving the teaching of Environmental Science across three sites.

The model adopted for this project was a student centred group based teaching and learning model with students taking considerably more responsibility for their learning than previously. Students were required to work in groups and select topics for presentation to colleagues from the broad content areas of the subject. Other class members were informed of the topics so that they could become familiar with the content areas in order to participate in discussions and in a peer assessment process.

Students felt that they learnt the topic selected for presentation well and thorough understandings developed through the need to explain and discuss the subject material with other class members. The preparation for the presentations enabled the students to come to grips with the subject matter in order to be able to articulate it to their peers and lecturers. In spite of this, students felt that they learnt little from other students' presentations. This indicates a possible reliance on "the expert". Many students still expressed a need to learn the "right" information from the "guru". Few students trusted the information they were receiving from their peers as being the "correct" information. This view tended to make them somewhat less interested in presentations other than their own. It also demonstrated a contradiction as they felt that the learning which resulted from the preparation for and the delivery of their own presentations was of a high standard, particularly as they needed to understand the subject matter well, in order to "teach" it to their peers. However, students did not place the same value on the presentations of their peers.

Another problem that students expressed with this approach was the difficulty they experienced in differentiating between the quality of the presentation and the quality of the content in the presentation. Sometimes a competent presentation - good layout, high quality graphics and a polished and personable style of delivery masked an underlying lack of depth of research and preparation of the topic. Students also commented that the need to concentrate on the presentation, for peer review purposes, inhibited their ability to understand and absorb the content of the presentation. This then resulted in a difficulty for students in asking meaningful questions. While such a model of teaching and learning can be successful, students unfamiliar with taking responsibility for their learning require considerable preparation and support.

**An identified need for staff and student development**

Development of the CUTSD and environmental science projects was carried out in parallel, so that there was little sharing of ideas across projects. However, while it was intended that the subjects offered as part of the CUTSD project be offered in a fully interactive teaching and learning manner, as with the initial project described here, feedback from the students indicated that this was not the case. Interaction tended to be sporadic and dependent on the style and experience of individual lecturers, particularly with videoconferenced teaching and learning. Students felt that experience in using videoconferencing was a critical factor in developing a fully interactive teaching and learning session. The students from Deakin University commented that they had seen great improvements in videoconferencing by Deakin lecturers as they gained more experience, understanding and confidence in teaching using this medium. Additionally, this point was commented on by the Northern Territory University (NTU) students who also felt that experience was a critical factor in successful videoconferenced classes. In a previous paper Klease, Andrews & Druskovich (1996) reported that the time and opportunity to develop skills and experience was a critical part of the staff development process for effective use of videoconferencing, a finding that is reinforced by students' comments.

The students further commented that for an effective teaching and learning model there was a need for good organisation and planning on the part of the lecturer. Students need to clearly understand the requirements and expectations of the unit or part of the unit being offered, particularly those offered by Universities or agencies other than the one the student is attending. This not only helps the student to determine if participation would be beneficial, but can also assist in overcoming timetabling problems, which can pose considerable impediments to this type of inter-University collaboration.

Students involved in the videoconferencing projects recognised the need for themselves to be familiar with videoconferenced teaching and learning environments in order to operate more effectively within them. The more experience they had in these environments, the more comfortable they felt in contributing to the teaching and learning activities. This is in keeping with the need expressed by staff that time and familiarity with the medium are important aspects for developing effective pedagogies.

As such, student preparation was seen as an integral part of success in the development of virtual faculties using videoconferencing. Students commented favourably on training programs that assisted with activities such as presentations and subsequent discussion sessions. They also requested the opportunity to revisit information that assisted them in working in these environments and to have this information available on an ongoing basis eg on a Web page. This request was implemented and students were able to seek further support from this source if required.

**Access to lecturer**

Students expressed a need to be acquainted with and have access to the lecturer. Where the lecturer was a stranger to the students they felt very reluctant to ask questions or to ask for assistance with any difficulties they might be having. In cases where they did not know the lecturer they often preferred to ask their local lecturer/tutor for assistance even thought they were aware that this person did not have the same content expertise as the lecturer conducting the sessions.

Research from several CQU projects, including those associated with Science, have clearly demonstrated the need for students to meet with the lecturer early in the semester if at all possible. This is supported by other research in this area (Musial & Kampmueller, 1996; Ostendorf, 1994). Where this is not possible, students have suggested that an "informal, get to know you" session, using videoconferencing, would be of considerable benefit. Such sessions would be most effective if conducted in some structured manner. Spontaneous and informal conversation is very difficult to manage using videoconferencing as there is no facility for participants to break into small groups, which is the usual nature of such interactions. Organising a series of structured icebreaking and information sharing activities can provide some basis for shared experience and knowledge of the participants that can be brought to the classroom environment. This can facilitate an awareness of the background knowledge and understandings student bring to the proposed teaching and learning session and possible gaps in these areas.

### Technological Issues

Technological problems are a major hurdle to the development of successful videoconferenced environments. Students involved in the CUTSD project commented that it seemed as though not one single videoconference link was without some kind of loss of signal. This meant that the time left for the lesson was often reduced. Local tutors were unable to continue the lesson as they were unfamiliar with the specialised content areas. Generally it was not known who was dealing with the problem, whose responsibility it was to try and reconnect or how long it might take for the problem to be resolved. Technical problems seem to be more common in multi-point conferences, than in point -to -point conferences which are often trouble free.

Students involved in cross-campus projects also found that technical problems were one of the major causes of frustration. Again the biggest concern was with reduced teaching time and limited access to the lecturer. However, in cross-campus activities there is more possibility for local tutors to be able to provide academic support in case of technological breakdown. Loss of contact results in losing the flow of the presentation or interaction and reducing students ability to ask questions and deal with the content in a meaningful way. Even after reassurance by staff that there was sufficient time (in most cases) to cover material, this was still of considerable concern to students who felt that every minute was precious.

## Points for Consideration

Student feedback strongly supports earlier research (eg, Schiller & Mitchell, 1993) that a traditional lecture mode of teaching and learning is the least preferred model. This highlights the need for staff involved in videoconferencing to develop an awareness of and competency in teaching and learning models that are suited to the technology they are using. This may mean that staff will need to undertake professional development activities geared towards assisting them in developing teaching and learning models more suited to videoconferencing.

As part of developing an understanding of effective pedagogies for videoconferencing, there needs to be an awareness that there is not one "magical" model. In selecting an appropriate model for videoconferenced classes, lecturers need to take into account several factors including, the number of sites, the number of students at each site, students previous educational background, students experience with videoconferencing and the subject matter to be taught. For example, in situations where the student numbers are large and students have little previous experience of student centred teaching and learning models, the group work model may not be successful. On the other hand where student numbers at each site are small and students have the opportunity to gain skills in group work, this can be a very successful model resulting in students asking for more rather than less group learning activities (Luck et al, 1998).

Student preparation for using videoconferencing is an important consideration in developing effective pedagogies. Levels of familiarity with and expertise in the use of videoconferencing and possible associated teaching and learning activities, for example, more student centred teaching and learning, will vary widely from site to site and student to student. Increased familiarity with and confidence in using technology and in student centred approaches to teaching and learning can promote transparency of the technology. As a direct outcome of both pedagogical and technical preparation for videoconferenced classes, students have shown an enthusiasm to participate actively and openly in subsequent videoconferencing activities.

## References

Comeaux, P. (1995). "The impact of an interactive distance learning network on classroom communication". *Communication Education*, Vol.44.

Klease G., Andrews, T. & Druskovich, D, (1996) "Blurring the Boundaries - Developing Effective Teaching/Learning Models for Multi-site Videoconferencing" *in Proceedings 2nd International Conference on Open Learning*, Open Learning '96, 4-6 December, Brisbane.

Luck, J., Andrews, T., Jewell, R., Schlotzer, A., & Madsen, M. (1998) "New Technologies: New Skills Development" to be published *in Proceedings 3rd International Conference on Open Learning; Open Learning '98 - Offering New Directions*, 2-4 December, Brisbane.

Musial, G. & Kampmueller ,W. (1996) "Two-way Video distance Education: Ten Misconceptions about Teaching and Learning via Interactive Television", *Action in Teacher Education*, Winter, 17 (4).

Ostendorf, V. (1994) *The Two-way Video Classroom,* Littleton, Colorado; Virginia Ostendorf Inc.

Schiller, J. & Mitchell, J. (1993) " Interacting at a distance: staff and students perceptions of teaching and learning via videoconferencing" *The Australian Journal of Educational Technology* 9 (1).

## Acknowledgments

These projects were supported by funding from the Committee for University Teaching and Staff Development (CUTSD), and Central Queensland University teaching development grants.

# WHAT'S IN ALL THOSE PIPES?

**Ted Lister**

*The Royal Society of Chemistry, Burlington House, Piccadilly, London, W1V 0BN, UK*

**Abstract**

This paper describes some of the activities of The Royal Society of Chemistry in the UK to produce materials for use in schools, which deal with industrial chemical issues.
The *Industrial Chemistry for Schools and Colleges* video: a video of 12 five-minute clips of the major bulk industrial processes.
*Industrial Case Studies*: a book of studies, written in collaboration with the industries involved, which explores the themes: the chemical industry and the environment; the economics of the chemical industry; and scaling up from bench to factory.
*Teacher Writing Workshops*: professionally edited and produced material for use in the classroom written by teachers following a visit to a chemical company.

## What's in all those pipes?

Most people's image of the chemical industry is probably of a large "wasteland" site covered with an incomprehensible jumble of pipes, most of them rusty . The chemical industry can sometimes present a dismal prospect.

**What do they *do* in there?**
This is probably the first question that a school student would ask when confronted by a chemical plant.
"We make sulphuric acid" might be the reply.
To a chemist this is a satisfactory response – *we* know the enormous variety of end products to which sulphuric acid contributes and we probably remember the famous quote from Liebig about judging the prosperity of a country by the amount of sulphuric acid that it consumes.

"You will perceive that it is no exaggeration to say we may fairly judge the prosperity of a country from the amount of sulphuric acid it consumes." – *Familiar Letters of Chemistry:* Justus Von Liebig, 1843.

However the term sulphuric acid has a rather different connotation to the lay person – ideas such as "acid rain", "poison", "corrosive", "danger" come to mind. Our questioner will never have bought any sulphuric acid and nor is she likely to do so knowingly. Understandably, people in general and children in particular are more interested in the final product – make-up, cars, paint, fertiliser etc, are rather more interesting than slightly viscous coloured liquids. So we need to stress the desirable end product rather than its less attractive beginnings.
Industry itself is concerned about the problem but often doesn't know how to go about things. The resources it produces are sometimes poorly targeted and speakers often don't understand how to talk to audiences of young people. Masses of educational resources are produced by the chemical industry. Often they are beautifully and

expensively produced but many are not correctly targeted with regard to level, language, curriculum and so on.
We are not, of course, trying to make our students into chemical engineers (not many of them anyway), or even chemists, merely people who appreciate the place of chemicals and the chemical industry in our society and see it in a positive light – exciting, challenging, wealth creating – rather than as some sort of devil's workshop. This is education in the broadest sense of the word.

## Royal Society of Chemistry initiatives

The Society has set up a number of initiatives to help teachers with the teaching of industrial chemistry:
1. The Industrial Chemistry for Schools and Colleges video
2. The Industrial Case Studies book
3. Teacher writing workshops.

### 1. The Industrial Chemistry for Schools and Colleges video

"Let's make a video." Before doing so, we did some research among teachers. Two things came out of this:
- Teachers wanted short clips to support their own teaching, not long and detailed films . Trends in the classroom had changed.
- Secondly, there was lots of material already out there, much of it made by companies, but much of it was dated. Nothing turned students off more than to see kipper ties and funny looking old cars in the car park.

Because of what is on school syllabuses, we decided to concentrate on bulk chemicals. All nine companies we approached agreed to co-operate in both research and filming.

### The clips in the video

Aluminium extraction
Ammonia manufacture (Haber process)
Chemicals from salt (electrolysis of brine)
Copper refining (electrolytically)
Fractional distillation of liquid air
Iron and Steel
Nitric acid
Nylon
Petrochemicals
Polythene
Sodium manufacture
Sulphuric acid

### Some problems and solutions

The scripts and storyboards were trialled with a number of teachers as was an almost-complete version of the video. Many teachers did seem ill-informed and/or out of date on many industrial areas. Perhaps we should not be too surprised, as industrial topics are not covered in many chemistry degree and initial teacher education courses. Misconceptions abounded such as that in the Haber process, equilibrium is reached in the converter. These are sometimes reinforced by exam questions which are not based on true situations and there is danger of a mythology developing.

To increase the potential life of the video, we consciously tried to avoid current fashions, hair styles *etc*. This wasn't difficult – hard hats and goggles don't date - but we did get a nice collection of old computers.

Two further problems were ethnic minorities and women – specifically the lack of them. During research and filming, both these groups were conspicuous by their absence. Occasionally non-white faces were seen doing menial tasks and women were present in plant almost invariably as cleaners or secretaries – not the role models we wanted to present. We toyed with the idea of using actors/actresses but after much soul searching we decided to "tell it like it was".

technical problem which we experienced was that the five electrolytic processes all used high electric currents – up to 200 000 A. These caused high magnetic fields in the plant – enough to affect the heads of a video recorder and a video camera. The film company solved this by using a mini camera based on a charge-coupled device (*ie* non-magnetic) which was connected to a video recorder by about 30 m of screened cable. The video recorder itself was kept in a specially constructed iron box to screen it from the fields.

**2. The industrial case studies book**

This is aimed at teachers – to inform and update them and it can also be used with post-16 year-old students. Industrial Chemistry is one of the areas where teachers seem to be least well informed and it is becoming increasingly difficult to organise visits within modern health and safety at work legislation.

It was particularly intended to tackle three points

- Environmental aspects of the chemical industry
- The issues involved in scaling up from laboratory to plant
- The economic dimension – this was the area where companies were most reluctant to supply information.

**The case studies**

Formulation of pharmaceuticals and agrochemicals
Development of an agrochemical (the fungicide azoxystrobin)
Environmental improvements in the iron and steel industry
Analytical chemistry: soil contamination and predicting wear in heavy plant
Discharge of radioisotopes into a river estuary
Scaling up the manufacture of a cable sealing compound
Scaling up the manufacture of a drug
Environmental issues in designing and constructing a 400 km pipeline for ethene

These issues were identified as potentially interesting by brainstorming among a number of chemists and chemistry educators and then identifying an individual or group of individuals within a company which was prepared to help. I then visited the companies and "interviewed" the individuals after which I wrote up drafts, which were trialled by teachers and commented on by the companies. This meant that the material

was of direct use to teachers and that its production did not take up vast amounts of time for the company personnel involved.
The material incorporates questions and its style is such that it can be used in a number of ways:

- by teachers for their own information
- by students individually
- as comprehension exercises
- by students for revision of chemical principles in novel contexts.

**3. Teacher writing workshops**

The RSC has organised *Industry Study Tours* for many years with the aim of refreshing teachers' knowledge and understanding of some aspect of the chemical industry. They have involved a small group of teachers visiting a plant for a presentation, tour and discussion. However, this can only make a small impact – on the teachers who actually attend and, hopefully, some of their colleagues and students. The idea of writing workshops is that the teachers who attend are expected to brainstorm some ideas for using in the classroom what they have learnt during the visit and then actually write (or at least draft) some material to be professionally edited, produced and circulated to schools.
Who better to give other teachers what they want and get the level right? The scheme also has the advantage of honing the teachers' writing skills and giving them the cachet of being published authors.
To date we have done five:
A company which produces "biodiesel" from rape seed oil
A company which produces "smart materials" such as shape memory materials and conducting plastics
A company which produces platinum
A company which smelts zinc
A company which makes zirconia.
The outcome is a book of up to date material based on a variety of chemical industries which includes suggestions for lessons, exercises and homework, all of which can be used directly by teachers.

**Conclusions**

- The chemical industry does not have a very positive image amongst young people.
- Teachers are keen for more up to date information about the chemical industry so that they can teach about it more effectively.
- The RSC has started a number of initiatives aimed at informing teachers about current issues in industrial chemistry and supporting the teaching of it.
- Companies have shown a great enthusiasm for being involved in these initiatives provided the demands made upon them are not too great.
- We need to know what teachers want and what they will use in the classroom.
- We need to involve teachers as much as possible.

# NOT JUST WHITE COATS AND TEST TUBES

**Ted Lister**

*The Royal Society of Chemistry, Burlington House, Piccadilly, London, W1V 0BN, UK*

**Abstract**

This paper describes two initiatives run by The Royal Society of Chemistry in the UK which show young people (and their parents) the role that chemistry plays in their everyday lives. It will attempt to raise and discuss some general issues involved in putting chemistry and chemists across to the general public (particularly young people).
*Chemistry at Work* events provide a stage for chemists from a variety of local organisations to get across to groups of young people from schools in their area what they do and how they enjoy doing it.
*Chemistry is Fun for Parents Too* is a series of workshops with demonstrations and hands-on activities for 8-11 year olds and their parents which aim to make chemistry accessible to as many people as possible.

**How are chemistry and chemists perceived?**

Many children (and a lot of adults) do not fully appreciate the extent to which chemistry contributes to their lifestyles. We, as chemists and chemical educators, have probably asked an audience to imagine that all the items in the room made by chemists disappear. There would be no plastic chairs, no metal chair legs, no pigments for paints and dyes, no glass in the windows and no electricity (for lack of copper wire and plastic insulation) and certainly no silicon chips for computers. Also, of course, without modern drugs, there would almost certainly be a smaller audience.
Chemists themselves (that is *ourselves*), are sometimes thought of as "nerds" in white coats who inhabit some other planet and may be thought of as less creative than professionals from the arts side of the academic divide. So chemistry can always be helped by good presentation. This is not only to recruit creative thinkers into chemistry but to extend an awareness of chemistry's importance and central place in the lives of everyone.

**What can we do about it?**

The Royal Society of Chemistry in UK has two schemes which are designed to help put across to young people (and their parents) just where chemistry fits in with their lives and how exciting it can be. These are:

1. Chemistry at Work
2. Chemistry is Fun for Parents Too.

## 1. Chemistry at Work

Most Chemistry at Work events are aimed at 13-15 year olds. This is an age group when children in the UK educational system have to make some choices about their future options. (There have been events for older students and the first one for primary school children (up to age 11) is taking place during this conference.). They take place over one, two or three days in a venue such as a school, college or university – anywhere with a group of rooms or a large hall. Six to 12 local organisations which use chemistry in their work are each asked to put on a presentation (as interactive as possible) about how they use chemistry. Schools are invited to send groups of about 15 pupils (with a teacher) to spend half a day at the event during which they will see about six different presentations. Ideally organisations will be local and presenters will be young. Both sexes and a variety of ethnic groups will be represented so that all students can relate to the presenters. Organisations should be as varied as possible to present the widest possible view of chemistry's place in the world.

The content of the presentations will be varied (see the list below). It will be based on the students' existing chemical knowledge but may range beyond the confines of the curriculum they are studying at school. It will complement the work done by pupils in schools by offering a taste of how chemistry is done in the real world. Examples of this might include:

- apparatus and techniques not encountered in school
- the economic dimension of chemistry
- chemistry outside the laboratory
- chemists dealing with the public.

Individual events are organised by the Society's Local Sections, which cover the United Kingdom but The Society employs a national co-ordinator whose job is to help get new events off the ground and cross fertilise ideas. Often an event's driving force is a teacher (from school, further or higher education). Organisations called Education Business Partnerships, whose function is well described by their name, often help with the administration.

The Society funds these events to the tune of £1500 (about $3700) for a three-day event. This is to cover administrative costs. Presenters are not paid, nor do we cover the costs to schools of getting pupils and teachers to and from the event – these have to be found by the schools themselves. Pupils get to take away a booklet with a page by each organisation to remind them of what they have seen and so that teachers can do follow-up work back at school. Before events we offer short training sessions to help presenters target their presentations to the right age group.

Examples of organisations which have put on presentations include:

A local dry cleaner

The army – testing fuels before filling up your tank (in both senses of the word)

The police – forensic science and measuring blood alcohol

The fire service – the chemistry of fire (and extinguishing it) and dealing with chemical spillages

Water companies – treating and testing drinking water

Breweries

A college teaching a course on cosmetics

A nuclear reprocessing facility

Drug and agrochemical companies

Manufacturers of bulk and speciality chemicals
The following points have been gleaned from experience:

- Variety is important. One can imagine many students being interested in the armed forces, police and fire services, for example, who would not see themselves as "academic" chemists.
- The aim of Chemistry at Work is not recruitment but an appreciation of the part chemistry plays in our world, how it underpins "non-chemical" activities and that interesting people earn their living as chemists.
- Each event has a local perspective so that students might find out for the first time what goes on in the factory round the corner or that to be a firefighter you need some understanding of chemistry. They will also be able to hear and talk to local people who work in chemistry and are enthusiastic about what they do.

**Do they work?**
We do try to see if our money is well spent. Each event is visited as one can get a feel as to how well it has gone – was there a "buzz" about the students who attended? Secondly, we have commissioned professional market research to find out how children's attitudes have been changed by attending an event.

**Some quotes**
The following quotes recorded following an event in the south of England indicate that there are potential gains for all involved in Chemistry at Work events – students, teachers, presenters and employers.
"There was still a big buzz when we got back to school and the children are still talking about their experiences." – Ian Thomas, teacher.
"It showed you chemistry could be fun." - Gemma Mullins, pupil.
"I really enjoyed the event. It improved my skills and confidence at giving presentations which was valued by my employer too." – Lucy Matthews, presenter.

**Market research**
90% of students rated events "interesting" or better.
Almost half of children who had visited an event said that they were more likely to consider a job in the chemical or pharmaceutical industries.

## 2. Chemistry is Fun for Parents Too

These events are aimed at 8-11 year-olds accompanied by their parents. They usually take place in a secondary school for a couple of hours in the evening. The school itself usually sees the event as good a public relations exercise among its feeder schools (most UK secondary schools are in competition for pupils) while the chemistry department sees it as an opportunity to foster a sense of excitement about science, especially chemistry.
A programme of experiments (both hands-on and demonstration) is put on including such things as popping hydrogen, freezing various materials in liquid nitrogen, flame colours *etc*. The success of these can be gauged from the fact that one teacher reports seeing parents pushing their own children out of the way in order to do the experiments first!

Although the experiments are chosen to be fun, easy to do and colourful, the programme does have themes:

- The world is particulate
- Chemists make new and useful materials
- Chemists test things to check that they are safe.

**Conclusions**

- Chemistry does not have a good image in with the general public and young people in particular.
- The two RSC initiatives described seem to have helped to redress the balance.
- These are relatively low-cost, easy to organise and reach large numbers of students.
- They are local events but within a national framework.

# COORDINATING THEORIES AND EVIDENCE IN CHEMISTRY CLASSROOMS

**Campbell J. McRobbie**

*Centre for Mathematics and Science Education, Queensland University of Technology*

Abstract

This research investigated student reasoning in a Year 12 chemistry classroom with a focus on students' thinking with and about the theory of equilibrium. Data sources included video- and audio-recording of classroom transactions; stimulated recall by students; and a survey involving student reasoning about possible explanations and evidential support. The research showed that many students had considerable difficulty in thinking with and about the theory of equilibrium and the classroom learning environment was not conducive to the development of such thinking skills.

Introduction

Both explanatory theories and empirical laws are central to the development of scientific understanding and explaining underlying mechanisms and processes of phenomena (Raghaven and Glaser 1995). It has been noted that while the derivation of empirical laws is common in science classrooms, there is less emphasis and opportunity for students to develop skills relating to thinking with and about science theories and models (Driver et al. 1996). Further, researchers have highlighted the need for educators to distinguish between the development of empirical laws and explanatory theories in classrooms "because the cognitive processes may be quite different" (Clement 1989, p. 337).

To think with and about scientific theories and the evidence that supports them requires an individual to be able to assess evidence independently of the theories they hold and to relate alternate possible theories to the evidence available (Duschl 1994; Kuhn, Amsel and O'Loughlin 1988). Kuhn (1993) has coined the metaphor of "science as argument" to describe this view of science reasoning.

Kuhn et al. (1988) and colleagues have reported an extensive series of studies indicating that students of all ages have difficulty in coordinating evidence with their beliefs or theories. Most of these research studies involved everyday beliefs unlike theories typically found in science classrooms and principally related to relational principles rather than explanatory theories. In a longitudinal interview study, Driver, Scott and Wood-Robinson (1994) did investigate science reasoning using typical science classroom concepts. They reported a predominance of phenomena and relational based reasoning at primary and lower secondary levels, with limited theory or model-based reasoning. However, these studies have not been conducted in the context of normal science classrooms. From a sociocultural perspective a student's actions which include their ways of reasoning, can be seen as resulting from interaction of the individual's goals, their beliefs and their construction of the context and their experiences (McRobbie and Tobin 1995). Accordingly, this study is conducted in the classroom context and relating to science theories normally encountered in that context.

The purpose of this study was to investigate student reasoning with evidence and explanations in the context of a Year 12 chemistry classroom.

## Design and Methods

The research reported here is part of a larger interpretive study (Erickson 1986) investigating teaching and learning in a Year 12 chemistry classroom (17 students) studying equilibrium and rates of reaction in a suburban high school in Brisbane. The design, data collection and analysis methods followed the procedures for quality constructivist inquiry as recommended by Guba and Lincoln (1989). Data sources included: interviews with students and the teacher; classroom observations and video and audio-recording of classroom transactions; stimulated recall of critical incidents in the classroom with students; classroom artifacts; and an interview with students on their coordination of evidence with explanations about chemical systems.

Previous studies by Roth et al. (1997) in Year 12 physics classrooms had shown students to be making observations and deriving empirical relations, but not seeing their practical activities in terms of theoretical concepts or science theories. Similar concerns emerged in this study about the levels of reasoning in this chemistry classroom. It was in this context that an instrument (Table 1) consisting of possible explanations (guided by common alternative conceptions (Garnett, Garnett and Hackling 1995) and evidence from a series of experimental situations was administered. After familiarisation, students were asked to choose the explanation(s) consistent with the evidence in each system presented and to justify their choice(s).

## Results

The results outlined here involve a triangulation of results from the explanation-evidence interview, stimulated recall of classroom transactions; student views on classroom transactions and researcher observations and field notes. All students subsequently received passing or higher grades in matriculation chemistry.

Firstly, Table 2 reports the results on the evidence-explanation interview corresponding to the items in Table 1. The mean score (all items) was 5.5 (SD 2.3) (maximum possible score was 10). Responses classified as "Other" included those such as, "That wouldn't happen, I don't think any one of the explanations applies" (Sally, Experiment 2b (Ex 2b)). With one exception, the students reported or demonstrated difficulties with determining appropriate explanations and justifying their choices.

Of particular concern was the kind of reasoning employed in justifying the selection of various explanation options. Only three students clearly demonstrated they were thinking with the equilibrium model, that is, they interpreted what was happening in terms of whether or not an equilibrium was involved and then applied the principles of the theory to justifying their choice of explanation. For example:

> Explanation 2 because they are still both reaching an equilibrium position but because they are at different temperatures...it is a different equilibrium position which would make the constant different as well...the constant is constant for a set temperature. (Jenny, Ex 2c).

Most of the other students did not demonstrate that they were thinking with the theory of equilibrium, mainly relying on linguistic cues and/or elimination to justify their choice, often noting that after eliminating explanations three and four on the basis of a change in ratio Q and both reactants and products being present at the final stage, that it must be "Explanation 2 because we have been told that the forward and backward reactions continue equally," (Matthew, Ex 2a) or "Explanation 2 because there must have been a reaction occurring so they are probably back and forward I guess"(Kerry, Ex 2a).

---

Explanation Options

*Explanation 1*: On initial mixing, there would be forward and back reactions until a stable position was attained. The forward reaction rate would then be equal to the back reaction rate and would both be equal to 0.

*Explanation 2*: On initial mixing, there would be forward and back reactions until a stable position was attained. The forward and back reactions would continue to proceed at equal rates not equal to zero.

*Explanation 3*: On initial mixing, there would be no reaction between the gases and the forward and back reactions rates would remain zero.

*Explanation 4*: On initial mixing, there would be a reaction in the forward direction with all reactants being used up and converted to product, at which time the forward and back reactions would each be zero.

Experimental Situations

*Experiment 2:* Two separate experiments were carried out. In the first of these experiments, 3 moles of hydrogen gas, 2 moles of iodine gas and 1 mole of hydrogen iodide gas were placed in a container; and in the second experiment, in another same size container, 4 moles of hydrogen gas, 4 moles of iodine gas and 4 moles of hydrogen iodide gas. After allowing for any reaction to occur and a stable state to be reached:

(a) If the final ratio Q for each container was found to have the same value, which in each case was different to the starting ratio.

(b) If the final ratio Q for each container was found to be different and in each case the same as the initial ratio Q for the particular container.

(c) The two separate experiments were repeated but at different temperatures and for each container the final ratio Q was found to be different from the initial ratio for that container and different from each other.

(d) The two separate experiments were repeated at different temperatures and the final ratio Q was found to be the same as the initial ratio Q for each container, but different from each other.

---

Table 1. The Four Explanation Options (1 to 4) and Four Examples (Experiment 2a, 2b, 2c and 2d) of the Experimental Situations Proposed as Evidence.

While only three students spontaneously proposed Explanation 1 as a possible explanation in relation to the evidence presented (for example, "I don't know whether the reaction has stopped or whether it is still going...there is not enough information given to decide (Gary, Ex 1a)), most other students accepted it when specifically asked whether the evidence presented enabled a choice between Explanations 1 and 2. Four students could not accept Explanation 1 as an explanation consistent with the evidence presented, noting that it was contrary to what they had been told in class. Such students might be said to have demonstrated an inability to think separately with their beliefs about the theory of equilibrium and the evidence presented.

Evident in the justifications and in the choices made were many of the alternative conceptions previously reported in the literature (e.g., Garnett et al. 1995) including, assuming all mixtures reach a chemical equilibrium state; confusion of the Q and K ratios; dependence of equilibrium constant on initial concentrations ("That would be saying that regardless of how much was there (to start with), it is reaching the same equilibrium constant...it depends on how much you put in doesn't it?" (Carol, Ex 2a)); and, a static model of equilibrium.

| Item number | Explanation 1 | Explanation 2 | Explanation 3 | Explanation 4 | Unsure | Other |
|---|---|---|---|---|---|---|
| 2a | 4 | 9* | 0 | 2 | 5 | 2 |
| 2b | 1 | 1 | 12* | 0 | 3 | 2 |
| 2c | 6 | 7* | 0 | 2 | 5 | 0 |
| 2d | 2 | 2 | 8* | 2 | 5 | 0 |

Table 2. Frequency of Selection of Explanations Listed in Table 1 (N=17). (Students were allowed to propose more than one explanatory statement.)

A particularly interesting case was that of Larry, a high achieving student rated in the top one percent of the state at matriculation, and the highest achieving chemistry student in the class. Larry showed the first two of these alternative conceptions.

In Ex 2b, Larry assumed the system would change towards an equilibrium composition in spite of the evidence presented. After the interview he admitted assuming each system involved a reaction towards an equilibrium composition and trying to apply the mathematical expression for the equilibrium constant. His reasoning showed how he was unable to separate these beliefs from the evidence presented and how he subsequently struggled to rationalise those beliefs. (In other items he indicated he was aware of the dependence of the equilibrium constant on temperature.)

> I really don't get how they (the final Q ratios) couldn't be equal, because they are at the same temperature. I suppose that suggests that temperature doesn't necessarily affect the equilibrium constant?... I just can't think hypothetically like this, because it upsets everything I know, and if the temperature is the same, the equilibrium constant would not be dependent on temperature necessarily.

The assumption that all systems involved a chemical equilibrium was common, for example, "Doesn't equilibrium happen with every thing, every reaction unless it is an open container where it can go until it is finished?" (Holly), and, "I am assuming that they are going to be equilibrium reactions, I kept thinking the reactions had to go forward and backwards, I don't know why, I guess that is what we studied in class" (Nan).

It was surprising that such a talented student as Larry would have such difficulties in answering these questions after studying the equilibrium topic. After completing the interview he commented further:

> I sort of had trouble when the results contradicted what happened in the real world, I tried to apply the same rules and didn't sort of change my theories to suit the new ... I would have to change my theory if some of these situations came up in the real world...This is one of the hardest things I have done!...Because I have some idea of what should happen, I have trouble accepting the idea something else might happen.

Secondly, further evidence about the extent of thinking with the equilibrium theory was found in the stimulated recall with the students about their practical experiments, in particular, the iron III thiocyanate activity. Firstly, the teacher directions for the experimental activity were replayed to the students for them to indicate what they considered the teacher was expecting of them in the laboratory.

> The teacher is asking us to think about what is happening, why it is happening more so ... more asking us to focus on why stuff is happening instead of just blindly going through the experiment, this is like she usually says. (Jenny)

Then the students were shown a replay of their group conducting the practical activity and asked to comment on what they were thinking and talking about during the practical activities, showing phenomena based and some relational based reasoning:

> Actually, we were just looking at the colour changes, thinking about how intense the colours were...we did think about the concentration of the coloured one going up as the colour increased ... no, we were not focusing on what was happening at the molecular level when that was occurring. (Jenny)

Thirdly, student's comments on the nature of classroom transactions were supported by observations and field notes. Students commented that, "We are just told what the answer is, we are never asked about other possibilities (explanations)" (Kerry), and "No, we don't have these sorts of questions in class,... in class the questions are just more calculating things, more straight forward, just follow this formula kind of thing" (Carol). Observations and field notes by the researcher suggested that practical activities largely involved just recording observations; many of the practical activities or demonstrations conducted by the teacher were not integrated into further classroom discussion; and, the learning environment was characterised as a rule based approach, including extensive numerical problem solving, rather than the development of a conceptual understanding of the equilibrium model. There was little modeling of thinking with the equilibrium theory to explain phenomena nor opportunities for students to practise and test the viability of their reasoning in discussion with their partners or in a whole class situation.

## Discussion

These results show that most students in this class, including some of the high achieving students, had difficulty coordinating and justifying their choice of explanation to match the experimental situation. In this, they showed some of the difficulties reported by Kuhn et al. (1988) in their studies, which could lead to the conclusion that many students in this group were unable to coordinate their theories and explanations and justify their choices by thinking with the equilibrium theory.

On the other hand, a different interpretation emerges if one investigates the reasoning practices of the community in this classroom. A review of the learning experiences showed that all chemical systems considered were equilibrium reactions. At no stage were mixtures of substances that did not achieve equilibrium considered, nor how one would distinguish between mixtures of substances in a stable but non-equilibrium state and mixtures in equilibrium states. The Equilibrium Law was therefore able to be applied to all systems considered in class, which led students to expect that application of those principles they had learnt would be able to be applied to all systems encountered. Also, the Q ratio was not discussed nor distinguished from the equilibrium constant in class, further leading to the impression by students that mechanical application of the equilibrium law would be appropriate for all situations.

If students are not shown how, and do not develop the skills of reasoning with evidence and theories or explanations, they have little option but to learn and apply rules without understanding. An environment to develop such skills would be one in which teachers modeled the kind of thinking involved with a focus on coordinating different forms of evidence with explanations at phenomena-based, relational based and theory-based levels and encouraged students to be aware of the kind of explanation they were presenting. Students would discuss forms of evidence, say from practical activities and other sources, between themselves and between themselves and the teacher; and would make claims, thereby ensuring the evidence to support those claims was explicit to themselves, other students and the teacher, so the viability of their claims could be tested against alternative views.

This study shows how it is more fruitful to consider the science reasoning students employ arises as a result of the practices of the community in which they are learning to reason, rather than as a deficit model of their capabilities. It is also clear that these skills cannot be taken for granted in students even at the Year 12 level, and if students are to successfully be able to think with explanatory theories, discuss the viability of those theories in explaining phenomena, and to interpret laboratory activities in terms of science theories, then more systematic attempts should be made to develop these reasoning skills. This same point was echoed by a Year 9 student in a related study who commented, "They (the teachers) don't teach us how to explain, they only teach us other people's explanations."

References

Clement, J. (1989) "Learning via Model Construction and Criticism", in Glover, G., Roming, R. and Reynolds, C. (eds) *Handbook of Creativity: Assessment Theory and Research,* New York: Plenum, pp. 341-381.

Driver, R., Leach, J., Scott, P. and Wood-Robinson, C. (1994) 'Young Peoples' Understanding of Science Concepts; Implications of Cross-age Studies for Curriculum Planning', *Studies in Science Education*, vol. 24, pp. 75-100.

Driver, R., Leach, J., Millar, R. and Scott, P. (1996) *Young Peoples Images of Science,* Buckingham: Open University Press.

Duschl, R. (1994) "Research on History and Philosophy of Science", in Gabel, D. (ed.) *Handbook of Research on Science Teaching and Learning,* New York: Macmillan, pp. 442-465.

Erickson, F. (1986) "Qualitative Models in Research on Teaching", in Wittrock, M. C. (ed.) *Handbook of Research on Teaching,* 3rd edition, New York: Macmillan, pp. 119-161.

Garnett, P. J., Garnett, P. J. and Hackling, M. (1995) 'Students' Alternative Conceptions in Chemistry: A Review of Research and Implications for Teaching and Learning', *Studies in Science Education,* vol 25, pp. 69-95.

Guba, E. G. and Lincoln, Y. S. (1989) *Fourth Generation Evaluation,* Beverley Hills, CA: Sage.

Kuhn, D. (1993) 'Science as Argument', *Science Education,* vol. 77, no. 3, 319-337.

Kuhn, D., Amsel, E. and O'Loughlin, M. (1988) *The Development of Scientific Thinking Skills*, New York: Academic.

McRobbie, C. J., & Tobin, K. (1995) 'Restraints to Reform. The Congruence of Teacher and Student Actions in a Chemistry Classroom', *Journal of Research in Science Teaching,* vol. 32, no. 4, pp. 373-385.

Raghaven, K. and Glaser, R. (1995) 'Model-based Analysis and Reasoning in Science. The MARS Curriculum', *Science Education,* vol. 79, no. 1, pp. 47-61.

Roth, W.-M., McRobbie, C. J., Lucas, K. and Boutonne, S. (1997) 'The Local Production of Order in Traditional Science Laboratories: A Phenomenological Analysis', *Learning and Instruction,* vol. 7, pp. 107-136.

# BRIDGING THE GAP BETWEEN PROMISE AND PRACTICE: THE USE OF MICROCOMPUTER-BASED LEARNING IN SENIOR CHEMISTRY

**Campbell J. McRobbie and Gregory P. Thomas**

*Centre for Mathematics and Science Education, Queensland University of Technology.*

**Abstract**

Microcomputers are increasingly used in school chemistry laboratories for data logging, analysis of data, and the consequent development of understanding of phenomena. It is mooted that the successful implementation of such technology promises to enhance students' learning through faster and more reliable access to, analysis of, and interaction with experimental data. This study reports on a classroom where the promise of using microcomputers to enhance students' understanding of particle theory and gas laws was not fulfilled. Factors influencing the use of the microcomputer, and consequent less-than-expected levels of student understanding included the teacher's and students' beliefs about teaching and learning, the role of practical work in the chemistry course and the nature of the concepts being investigated. Suggestions for bridging the gap between the promise associated with the use of such technology and the reality of this contemporary chemistry class are proposed.

## Introduction

The National Board of Employment, Education and Training commissioned a review (Tinkler, Lepani and Mitchell 1996) which found that there was a generally low penetration of computers as learning and teaching tools into classrooms. The use of microcomputers in science laboratory activities is one promising application of computers as learning and teaching tools. Such an application is congruent with the goals in the Australian Science Statement and Profiles (Curriculum Corporation 1994a) and the Statement and Profiles on Technology for Australian Schools (Curriculum Corporation 1994b) in that it seeks to provide opportunities for students and teachers to explore and understand workplace applications of science, and the development of skills of investigation, reflection and analysis, to generate or refine knowledge, find solutions and pose questions. Increasing the understanding of the science that is studied and the development of higher level reasoning skills such as these are central to reform directions in science education (Bybee and DeBoer 1994).

Increasingly sophisticated Microcomputer-based Learning (MBL) systems are being purchased and used by secondary schools in their science laboratories for data logging, interaction with the student in the analysis of that data and the development of understanding of phenomena. Nachmias (1989; cited in Lazarowitz and Tamir 1994) suggests that this technology's potential to enhance learning lies in its ability to overcome barriers to learning including delays in processing results, observation of phenomena in multiple representations, and the capability of simultaneous multiple measurements. As most of the technical work is done by the computer, it is proposed that the student is more able to solve problems and employ higher order thinking skills, and that continuous interaction with the experimental data should aid in the identification of alternate conceptions and conceptual change. Lazarowitz and Tamir (1994), however, conclude that research is ambivalent as to whether the application of such technology does enhance learning. Many studies, e.g., Stein, Nachmias and Friedler (1990) and Nakhleh and Krajcik (1994), have involved a comparison of outcomes of varying degrees of MBL use. Few studies have investigated what students actually do and why they do so as they interact with this technology, how it influences their learning, and the significance of teacher and student variables such as beliefs about teaching and learning on the use of the technology. Hodson (1992) argues that until we study in detail what students actually do in laboratory activities, we are unlikely to understand the pedagogic value of laboratories in learning. Accordingly, the purpose of this research was to understand why teachers teach and why students learn as they do in a laboratory setting where the teacher is attempting to integrate MBL technology.

## Methods

An interpretive methodology, concerned with the immediate and local meanings of actions, as defined from the actors point of view (Erickson 1986, p.119) was adopted. The beliefs and experiences of the teacher and students were interpreted through the lens of constructivism. The benefits of the hermeneutic process, authenticity and trustworthiness, were important considerations in the study and the analysis of the data (Guba and Lincoln 1989). The class consisted of 12 males and 9 females studying Year 11 Chemistry in a metropolitan Brisbane independent school. Multiple data sources were employed which included: classroom transactions video-recorded with front and rear cameras; interviews with the teacher and students about the nature of practical work, teaching and learning, and the use of the computers in the laboratory setting before and after the use of the MBL technology; pre- and post-tests on the behaviour of gases and particle theory; stimulated recall interviews with individual students (O'Brien 1993) in which the recall of their thinking as they used the MBL technology was stimulated by having them view a split-screen image consisting of an image of their group superimposed on an image of the computer screen as it simultaneously appeared throughout the experiment. Six students spanning the range of students' views and chemistry achievement were selected for intensive study.

## Results

Anne (all names are pseudonyms) had taught for seven years. Prior to teaching she had, with a PhD in chemistry, worked in chemistry laboratories. For the past two years she had collaborated with the head of the school's science department to introduce computers into the chemistry laboratories for use in practical work. "We were asked to think about what we could do for teacher appraisal ...one of the things that was lacking in our labs was a computer which was linked up to experiments." The reasons Anne outlined for choosing the computer innovation were congruent with the promise for the use of such technology previously outlined.

> "We saw that it would definitely improve our teaching because the kids would be having a more varied experience...it would allow us to do things that we hadn't done before and give us more flexibility. It's so quick. You might do the prac two or three times over ...you can plot it straight away and you can immediately start talking about how the temperature and the pressure are related or how the pressure and volume are related. The results are so accurate compared to what we were doing before, and they will actually show you the mathematical relationship."

Anne spent the majority of class time, both before and after the practicals utilising the MBL technology, adopting a quantitative, rule based, algorithmic and mathematical approach to the study of gases claiming, "This unit of work is very mathematical." Her belief in the mathematical nature of this area of the curriculum strongly influenced her prime use of the MBL technology as a means of collecting data for use in verifying the gas laws. "Sometimes kids are very hard to convince but if they have the evidence in front of them, they have to be convinced, even if it wasn't what they expected." It was the sole function of the computer to supply this evidence.

By her own admission, Anne's teaching was very didactic and focussed on transmission of knowledge rather than having students construct meaning.

> "I feel most comfortable with a teacher-centred environment...I only feel comfortable when it's teacher centred. Part of that is my educational background. I come from an era when talk and chalk was the way you learnt. Part of it is very much that I want to set things absolutely straight...not let them go off with some stupid idea and fall in a heap because they haven't got the facts to start with."

Tempering Anne's enthusiasm for the innovation was an emerging awareness that use of the MBL technology was not as straightforward for the students as she initially expected. "We're still finding out things that aren't so flash because we're still in the early stages of using it. The kids aren't always totally aware of what they're measuring unless you really get them to say, "What is it that we're measuring?"

When introducing the two practical activities examined in this study, Anne used a very structured format. The aim of the experiment was outlined; apparatus specific to the experiment was introduced and its operation briefly explained; the variables being examined were clearly specified to students and briefly discussed at a macroscopic relational level; procedures specific to the experiment, for example ensuring that the volume of gas in the tube attached to the syringe was incorporated in the total volume of the gas, were identified. Students were given a very simple procedure to follow. Anne justified this level of direction stating, "...basically kids need a very brief procedure so that they don't have to do much of the delicate work. If you have nice simple instructions, one, two, three etc., they're much more likely to read it and follow it through." Missing from her introductions were references to how and why students' manipulation of the conditions under which the gas was contained affected the gas particles at a molecular level. Nor were students asked to relate changes in the macroscopic variables, measured using the computer, to simultaneous changes occurring at the molecular level as they altered the temperature or volume of the gas. In stimulated recall interviews students reported a similar interpretation regarding the focus of her introductions. Lisa, a high achieving student whose views were typical of those interviewed, recalled "She was talking about how the machines worked and stuff, and how we'd be working in groups on the computers, and how that should only take a certain amount of time. She's telling you what to do." Jon, a pass grade student from another group, suggested that following the introduction his focus was going to be to, "Just operate the computer programme. Just press the buttons."

Anne expected that, as the students did the experiments, they would be thinking,

> "Firstly, are they connecting it up properly; secondly, what are the results coming out and are they what you expected. They see it, and sometimes they think about it, but often they'll be given questions that they have to answer and that's when the thinking takes place, when they actually get home and they have to sit and answer those questions."

While clearly acknowledging the potential of the MBL she stated she was "quite accepting of the fact" that students would not be thinking critically regarding data as it emerged on the computer screen claiming "it's probably how my brain would have worked when I was that age. I know that I didn't look at data until I got home and I know a change happened during second year university and I wasn't really good at thinking about everything that happened as it was happening until third year." In her assessment of their practical work she concluded, "I'm happy with how they do their practical work. They organize themselves reasonably well and they usually do the task. If I could change anything, I'd like to see them do more work outside."

Analysis of data from the three groups whose use of the MBL was explored suggests that the students were almost exclusively concerned with, as they agreed in interviews, "following the recipe" of the practical as directed and obtaining the data. Within groups, the students allocated procedural tasks to each other then rigidly adhered to their task descriptions. In one group, where the division of labour was typical of all groups, as Jason read the instructions Neil manipulated the syringe while Jon operated the computer. Jason commented on the extent to which task allocation affected his behaviour and thinking claiming that in the Boyle's Law experiment his responsibility was to ensure that the instructions were followed. "If everything didn't run smoothly I knew that everyone would be blaming me because I'm the one with the instructions."

The single-mindedness with which students sought to obtain their data resulted in several consequences. In some cases, thoughtful and reasonable questions were ignored to ensure that the collection of data continued uninterrupted. Jason confirmed and exemplified this obsession for data collecting stating, "The emphasis was more on getting it done and then thinking about it later." Students' interaction with the data as it appeared occurred at only a superficial level. Cleo, working in a third group separate from those of Jason and Lisa, asserted that she did not think about what the figures actually meant because "she was concentrating on the experiment, what to do." In addition, students did not systematically or purposefully examine the multiple representations of data that were available on the screen in the form of tables and graphs. In stimulated recall interviews students unanimously reported not noticing coloured dots, representing the pressure of the gas at certain temperatures, as they appeared in a graph on the screen. These dots often became highly visible lines as the temperature of the gas came to the temperature of its water bath it and the pressure exerted by the gas changed accordingly. As the experiments proceeded no discussion on events occurring in relation to the gas at the molecular level took place.

Following their data collection, the students answered questions related to the practicals. In the case of the Boyle's Law practical they were shown by the teacher how to confirm the law from the data. As in the pre-experimental discussion, little in the way of cognitive scaffolding or modeling higher level processes was provided to the students. No discussion regarding data anomalies took place for either experiment. Questions following the practicals were predominantly of the type, "Express in words the relationship between gas pressure and temperature" and "Write the mathematical equation for the line." Only one question related to the temperature-pressure relationship of a gas, "Explain this relationship in terms of molecular velocity and collisions of particles" asked students to think beyond the relational level and seek to explain their data with reference to kinetic molecular theory.

Students differed with respect to the quality of the learning they believed resulted from using the MBL technology. Some students, for example Lisa and Jason, suggested that the practical added little to their understanding of gas behaviour. Lisa commented, "In the computer pracs I knew what to expect because we'd already done it in class. They're just backing up what you've already learned in the textbook. I would have still had the same understanding after a certain time from something else." Ruth, Lisa's partner and the top achieving student in the class, further confirmed this. When asked if using the computer had made any difference to her learning she replied, "No. I don't think so. I don't think they're as hands-on as we usually do. You're just clicking buttons rather than actually doing it." Sue, a member of Cleo's group, and Jon suggested they could have learned the principles without the computer pracs but that, as they both stated "...it wouldn't have been as clear." Significantly, some students' alternative conceptions, identified on a pre-test, remained unchallenged as a result of the use of the MBL technology. These included the belief that gas particles clump in the centre of their container or fall to the bottom of their container as the temperature is decreased, and that the volume of air in a syringe is not altered as the plunger is moved in and out.

In discussions with the researchers on the assertions emerging from the research Anne defended her use of the MBL technology stating, "...you have to really compare it to the experiments we did before...even the brightest kids had a lot of trouble getting anything out of them." She agreed that, "...the questions that were asked after the pracs asked them to come up with a mathematical relationship...I did spend time with them going through how to come up with a mathematical relationship" and conceded, "Now I know that half the class didn't really get to that, but that's what I would have ideally liked them to understand." After further reflection Anne suggested,

> "...it'd be good to have a question about why the pressure increased as the volume decreased, at the molecular level...because what we're really interested in is the computer helping the kids understand the gas laws at a molecular level and what their thinking processes are as they're doing it. I think we can improve on what we're doing and try to make them a little bit more reflective."

## Discussion

This study demonstrates that knowing and being able to articulate the promise of an innovation is not sufficient in itself to ensure that the promise becomes a reality in practice. It also further confirms the relation between teacher beliefs and their classroom practices (McRobbie and Tobin 1995). Anne's implementation of the MBL technology reflected her deeply held beliefs about the nature and level of thinking that should occur in her class's chemistry laboratory which were, in turn, based on her experience. Her practice represented a paradox between what she articulated was valuable in terms of her own developing learning processes at university, that is the investigation of data as it emerged during experiments, and her willingness to articulate and model such processes for students so that they could be apprenticed into this way of thinking in their high school chemistry laboratory. A view of teaching and learning consistent with objectivist epistemology influenced Anne's practice ensuring that rather than explore the full potential use of the computers, a use she communicated and aspired to, the computer served exclusively as a tool for replicating experiments that provided data for verifying already established laws. While the provision of quality data is an important consideration for teachers in their selection and use of experimental activities, the obsessive focus on data collection in these experiments resulted in an ideal opportunity for using the MBL technology as means of investigating students' alternative conceptions and enhancing learning being overlooked.

Students' use of the MBL technology and their related cognition were determined by the classroom context which was greatly influenced by, and strongly reflected, the teacher's beliefs. There was little impetus for students to use the technology in a manner identified in the literature regarding the promise of this innovation. While Anne claimed that she was trying to get the students to think, the evidence from students' use of the MBL supports the contention that its use in these experiments did little to encourage students to think about or discuss the data or its significance as it became available, or to consider relating changes in macroscopic variables to changes at the molecular level. Students' assessment of the value of the MBL experiments leads us to query the value of these experiments, in their implemented form, as learning experiences. Furthermore, students' use of the computer was not independent of the social context of the classroom with relationships between group members influencing individual behaviour. The social context of the laboratory should therefore be considered when implementing MBL technology. We also suggest that the teacher should focus students' discourse on constructing meaning that is consistent with the experimental evidence. Students should then compare this understanding with their individual understanding, at both macroscopic and molecular levels, as well as the theoretical fabric of the discipline.

This research proved valuable for the researchers and the teacher. Discussions regarding the emergent assertions between the researchers and Anne enabled her to begin questioning her practice and the beliefs on which this practice was founded. We propose that ongoing reflective dialogue is a key factor in facilitating the successful implementation of MBL technology. Teachers must understand why they teach as they do before meaningful conceptual and practical change can be achieved. The challenge for the authors is to collaborate with reflective, innovative teachers like Anne to assist them to become more aware of and reflective regarding their tacit beliefs about teaching and learning chemistry so they can reflect on the practices resulting from those beliefs. This reflective process is essential if teachers are to develop and modify their pedagogy in such a way that the promise of MBL technology as a tool for learning is realised.

**References**


Bybee, R. and DeBoer, G. E. (1994) "Research on Goals for the Science Curriculum", in Gabel, D (ed.) *Handbook of Research on Science Teaching and Learning,* New York: Macmillan, pp. 466-490.

Curriculum Corporation (1994a) *A Statement on Science for Australian Schools*, Canberra: Curriculum Corporation.

Curriculum Corporation (1994b) *A Statement for Technology for Australian Schools*, Canberra: Curriculum Corporation.

Erickson, F. (1986) "Qualitative Methods in Research on Teaching", in Wittrock, M (ed.) *Handbook of Research on Teaching*, New York: Macmillan, pp. 119-161.

Guba, E. and Lincoln, Y. S. (1989) *Fourth Generation Evaluation*, Beverly Hills: Sage.

Hodson, D. (1992) 'Assessment of Practical Work: Some Considerations in Philosophy of Science', *Science and Education*, vol. 1, pp. 115-144.

Lazarowitz, R. and Tamir, P. (1994) "Research on Using Laboratory Instruction in Science", in Gabel, D. (ed.) *Handbook of Research on Science Teaching and Learning*, New York: Macmillan, pp. 94-128.

McRobbie, C. J. and Tobin, K. (1995) 'Restraints to Reform: The Congruence of Teacher and Student Actions in a Chemistry Classroom', *Journal of Research in Science Teaching*, vol. 32, no. 4, pp. 373-385.

Nakhleh, M. and Krajcik, J. (1994) 'Influence of Levels of Information Presented by Different Technologies on Students' Understanding of Acid, Base and pH Concepts', *Journal of Research in Science Teaching*, vol. 1, no. 10, pp. 1077-1096.

O'Brien, J. (1993) 'Action Research Through Stimulated Recall', *Research in Science Education*, vol. 23, pp. 214-221.

Stein, S., Nachmias, R. and Friedler, Y. (1990) 'An Experimental Comparison of Two Science Laboratory Experiments: Traditional and Micro-computer Based', *Journal of Educational Computing Research*, vol. 6, no. 2, pp. 183-202.

Tinkler, D., Lepani, B. and Mitchell, J. (1996) *Education and Technology Convergence,* Canberra: Australian Government.

# ENHANCING CONCEPTUAL LEARNING IN ORGANIC LABS

**Mauro Mocerino**

*School of Applied Chemistry, Curtin University of Technology, GPO Box U 1987, Perth 6845, Western Australia. m.mocerino@info.curtin.edu.au*

**Abstract**

In the science and engineering fields a good understanding of the practical aspects of the discipline is essential. It is contended that if students are stimulated to critically evaluate the processes/techniques employed in a laboratory exercise, then they will understand more fully the rationale behind these processes. This should also lead to better practical skills and a better understanding of the concepts involved in the exercise. Some of the strategies which have been introduced at Curtin University of Technology to stimulate students to critically evaluate the experimental processes and concepts involved in each laboratory exercise are outlined. The effectiveness of these practices of using laboratory tests are discussed.

## Introduction

Laboratory classes are very complicated environments with a mixture of practical activities and theory coupled with a considerable amount of distracting information which often masks the important concepts of the class. To alleviate some of this complexity laboratory manuals are usually written with clear step by step instructions. However, this allows students to successfully complete experiments simply by blindly following the instructions, without any attempt to understand the processes involved. Some students are so concerned with "getting the right answer" that they often do not recognise what they are supposed to be learning from the laboratory. Furthermore, many students seem to regard laboratory work as something which must be endured and enter the laboratory class with the aim of carrying out the exercise as quickly as possible. It is rare that a student enters the laboratory with the attitude that the laboratory session is an opportunity to gather as much information as possible on the concepts/techniques involved.

## The Curtin Situation

Third year organic chemistry students spend five hours per week doing laboratory work. Each semester they have a choice of approximately 15 experiments which are weighted according to degree of difficulty or effort required (see Table 1 for examples of experiments available). These experiments cover a range of topics, and students may choose which of these to do and when to do them. Typically students do approximately eight experiments per semester. Before commencing an experiment, however, the student is required to submit a "prelab" which is signed by the laboratory supervisor. The prelab exercise is an important component of the experiment and carries 20% of the assessment for each experiment. It includes equations for all reactions involved, a list of reagents and quantities required, comments on the hazards associated with all reagents used and products obtained, a flowchart, answers to assigned prelab questions and finally the supervisors signature. The hazards section is a significant component and students are encouraged to consult the relevant material safety data sheets in preparing this section.

Upon submission of a laboratory report, students are given a short test which examines a few of the key concepts of the experiment. The whole concept of using laboratory tests is based on work done by Simpson (1993). The laboratory tests were developed because it was felt that students did not take advantage of the learning opportunities available in laboratory classes. These tests were introduced primarily to encourage (stimulate/scare.....) students to think more deeply about what they were doing in the experiment and they carry 30% of the assessment for each experiment. Students are also encouraged to discuss the experiment and any questions they have with their peers and the laboratory supervisor during the class. Each test consists of three or four short answer questions and usually takes approximately fifteen minutes to complete, although there is no time limit.

| **Experiment** [credit points] | **Experiment** [credit points] |
|---|---|
| Acetylferrocene [40] | Macrocyclic chemistry [60] |
| Beckmann rearrangement [50] | Meso-stilbene dibromide [60] |
| Conversion of (+)-limonene to (-)-carvone [90] | 6-Nitrosaccharin [40] |
| Determination of caffeine and theobromine in | Stilbene [50] |
| chocolates by HPLC [60] | Triphenylcarbinol [60] |
| Dicyclopropyl ketone [60] | Vegetable oil analysis [90] |
| Eugenol from clove oil [50] | Wittig-Horner reaction [50] |
| 1-Heptene [60] | Analysis of polymers by infrared [40] |
| Heterocycle [30] | Dilatometry [50] |
| Hofmann rearrangement [60] | Emulsion polymerisation [60] |
| Housefly sex attractant [80] | Mechanical properties of polymers [40] |
| Hydride reduction [50] | Viscometry [50] |

**Table 1.** A partial list of third year organic chemistry experiments

A well constructed laboratory test *must* relate directly to the experiment. The questions may include observations, mechanisms, pre- and post-lab questions, explanations, inferences, generalisations, predictions, calculations and anything else that is pertinent. The questions in the test should require the student to demonstrate an understanding of the experiment. For example, consider an experiment in which students were asked to add five millilitres of dilute sulfuric acid to a reaction flask. To encourage the students to think about the function of the acid, one could ask a question relating to the degree of accuracy required in measuring the volume of acid, or whether another acid could be used instead. If the questions are trivial, then there is no stimulus for the student to perform at a higher level. Students are still required to prepare and submit laboratory reports and these along with any samples prepared constitute the remaining 50% of the laboratory mark.

The intended outcomes of using laboratory tests included:

- students would work harder during the experiment in an effort to gain as much information as possible to answer potential test questions.
- Students would gain a better understanding of the chemistry involved in the experiments.
- Students would learn to link laboratory practices to theory (not always an easy task).
- The tests would provide a focus of the main points of the experiment.
- The tests would be a useful form of rapid feedback for both the student and the instructor.
- Tests would be a fairer form of assessment. Laboratory marks would be based on the students' understanding of the laboratory, not on their ability to produce write-ups.
- Laboratory work would be easier to mark.

## Evaluation

The use of post-lab tests in third year organic laboratories has only just been introduced and a formal evaluation has not yet been carried out. However, some students were informally quizzed on their opinions on the use of lab tests. In general students indicated that they preferred not to do the tests, but they acknowledged that the tests encouraged them to try to understand the experiments better. Many students saw the tests as assessment tools for theory which was covered in lectures and did not recognise that the questions were directly related to the laboratory. This inability to associate laboratory experience with theory has also been observed by others (Stensvold and Wilson, 1992; Nakhleh, 1994). Some thought that the laboratory work carried out was not adequately rewarded, especially given their perception that the tests were theory based. A pleasing aspect of the comments was the large number of times students indicated that the tests stimulated them to modify their behaviour for the better. Since the introduction of laboratory tests students were commonly seen reading and studying their laboratory reports before submission and would discuss their results with their peers. This behaviour was rarely observed previously.

## Conclusion

The laboratory tests have been useful in stimulating students to better performances in laboratory classes and in their understanding of the underpinning theory. This was evidenced in the enhanced quality of their laboratory reports, particularly their discussion of the chemisty involved. A more extensive range of suitable questions and better communication to the students, of the philosophy behind the laboratory test, will further improve the program.


## Acknowledgments

I would like to thank Dr Peter Simpson for his many helpful discussions and A/Prof Alan Jefferson and Richard Hecker for their help in preparing a question item bank and for their enthusiasm in implementing this program into the laboratory classes.


## References


Nakhleh, M.B. (1994). Chemical education research in the laboratory environment: How can research uncover what students are learning? *Journal of Chemical Education, 71,* 201-205.

Simpson, P. (1993), *A new approach to teaching and assessing practical work in upper school chemistry.* Perth: Science Teachers' Association of Western Australia.

Stensvold, M. and Wilson, J.T. (1992). Using concept maps as a tool to apply chemistry concepts to laboratory activities. *Journal of Chemical Education, 69,* 230-232.

# BRIDGING THE GAP: REGULATORS, CONSULTANTS AND INDUSTRY

**Mark J Paton**[a] and **David Miles**[b]

[a]*OTEK Australia Pty Ltd, 26/500 Seventeen Mile Rocks Road, Seventeen Mile Rocks, QLD 4073*
[b]*Queensland Department of Environment and Heritage, 160 Ann Street, Brisbane, QLD 4000*

**Abstract**

Better communication between industry, regulators and consultants is an important step in "Bridging the Gap". Industry has its own needs and production constraints which may not always readily fall in line with the policy objectives of regulators. While representatives of industry are involved in policy development the philosophy and endpoint objectives of regulatory agencies are often not made clear to industry as a whole. A pathway to achieve an endpoint may be put forward by a regulatory agency to an industry without real understanding of all the facets that make industry "tick". Industry is about getting things done and has to continually solve problems associated with this. If a regulatory agency clearly communicates an objective to industry then it is often best left to that industry to come up with the best means of achieving it. Consultants play a central role in assisting industry achieve regulatory objectives and this must involve an understanding of both parties needs and a facilitation of communication between both regulators and industry. A case study in relation to contaminated land legislation is discussed.

**Introduction**

The *Contaminated Land Act 1991* (CLA) provided the legislative framework for the management of contaminated land in Queensland until 6 July 1998 and included processes for the identification, investigation and remediation of contaminated land. Over 1,000 sites frequently including multiple individual lots, have been remediated since the commencement of the CLA in 1992.

The structure of the CLA did not adequately promote the management of contaminated land and has resulted in some unnecessary remediation, particularly of industrial land. There has been a perception in the community that all sites recorded on the Contaminated Sites Register were contaminated, unmanageable and required remediation. In fact, very few sites recorded on the Register posed a public health or environmental risk from their existing use.

In addition, recent developments in national and international contaminated land policies have emphasised the need to clearly distinguish sites that constitute an environmental or human health risk and require remediation (risk sites) from those that are likely to have some contamination but have a low probability of environmental risk under the current use of the land (low-risk sites). This separation of sites on a risk basis promotes the appropriate level of management of contaminated land and improves the communication of contaminated land information to the public.

**New Legislation**

*The Environmental and Other Legislation Amendment Act 1997* integrated the provisions of the CLA into the *Environmental Protection Act 1994* (EP Act). The EP Act now provides a central piece of legislation to protect the environment in Queensland in accordance with the principles of ecologically sustainable development. The amendments to the EP Act have adopted the national approach on issues such as lender liability and the separation of sites on the basis of risk assessment.

The EP Act minimises red tape for protection of the environment, reduces cost to business and provides the legislative framework to manage environmental impacts under the ecologically sustainable development principles. The legislation supports economic development by limiting lender liability for contaminated land and reduces overall costs in the development of industrial and commercial property by preventing unnecessary remediation.

The EP Act adopts the concept of site risk management through the incorporation of two registers for the recording of land. The legislation distinguishes between sites which are likely to be contaminated but have low probability of risk to human health or the environment under the current land use (low-risk sites), and those which do constitute an environmental risk and require clean-up (risk sites). Low risk sites will be recorded on an Environmental Management Register (EMR). Risk sites will be recorded on a Contaminated Land Register (CLR). The vast majority of sites previously recorded on the Contaminated Sites Register of the CLA, are now recorded on the EMR, removing the "stigma" associated with contamination for low-risk sites.

Financial institutions expressed concerns about potential liabilities under the CLA where the institution became the owner of the land as a result of exercising security over the land. This has caused a negative impact on lending for sites recorded on the current Contaminated Sites Register, resulting in landowners and developers having difficulties in obtaining finance under certain situations. To address this issue, the legislation now limits the liability of financial institutions in order to facilitate normal trading with such land. Mortgagees will not be liable for land contamination that has occurred prior to them taking control of premises. This limitation applies where the financial institution does not have the exclusive management and control of the land. The EP Act also limits the circumstances in which the local government may be required to conduct or commission a site investigation or remediation work.

The new legislation also encourages the management of on-site contamination through site management plans, with particular benefits to commercial and industrial land, by ensuring that development capital is not wasted on unwarranted clean-up. In keeping with the focus on management of land contamination, the EP Act establishes site management plans to enable land which has some contamination to be used subject to plan conditions. These plans will provide considerable savings for industry and obviate the current tendency to remediate industrial land to unnecessarily high standards. Such land will be recorded on the EMR.

Appeal provisions were limited in the CLA. The new EP Act removes those limitations and provides review and appeal provisions for dissatisfied persons such as landowners and persons required to remediate land.

Under the new legislation, the review of site investigation reports, validation reports and approval of site management plans by Queensland Department of Environment and Heritage (DEH) will be in compliance with the development application requirements of the *Integrated Planning Act 1997.* This act sets the process by which land subject to a development proposal is referred to relevant agencies for their approval or otherwise and for the local government in the main, to then issue a single development approval to the applicant.

In addition the Department of Environment and Heritage released draft guidelines for the assessment and management of contaminated land in Queensland in May 1998 to support implementation of the new legislation.

**A New Era for Industry**

The DEH draft guidelines for "The Assessment and Management of Contaminated Land in Queensland" released in May 1998 contain for the first time detailed health based criteria. Previously the DEH Guidelines set Environmental Investigation Thresholds and only a few health based criteria (eg. lead, arsenic, cadmium and polycyclic aromatic hydrocarbons). The health based levels stated were derived from a conservative residential Dutch setting and had little or no relevance to industrial sites. The new health based criteria are applied to four typical Australian exposure settings. One of these settings relates specifically to industrial and commercial use. Industry, regulators and consultants can now evaluate contaminant levels for specific industrial sites with respect to both human health and the environment. The DEH Environmental Investigation Thresholds are generally much lower than the new industrial levels. In the past the tendency was to clean up to either environmental or to the residential health based levels.

A new approach to the clean up of industrial sites should now emerge. This fundamentally should give rise to on-site clean up and treatment where practical and feasible, to off-site treatment where options are available, to disposal only where no other options exist and in those cases where it is appropriate to be managed on site with a specific Site Management Plan. The old clean up strategy of dig and dump to landfill should therefore reduce dramatically and assist the State in achieving the agreed national target of a 50% reduction in waste to landfill by the year 2000, based on 1992 data. The increase in tipping fees and greater public acceptance of managed sites on the new Environmental Management Register will further assist this.

## Conclusion

The challenge has been set to "Bridge the Gap" and it is now up to industry, developers, consultants, the financial sector and government to use the contaminated land management provisions for the benefit of all in meeting that challenge.

## References

Contaminated Land Act 1991, Queensland
Environmental Protection Act 1994, Queensland
Integrated Planning Act 1997, Queensland
The Environmental and Other Legislation Amendment Act 1997, Queensland

# WHAT LABORATORY RELATED SKILLS DO EMPLOYERS WANT FROM CHEMISTRY GRADUATES?

**I.R.McKinnon[b], E.K. Nunn[b] and A. F. Patti[a]**

[a] *School of Applied Sciences, Monash University, Berwick campus, Clyde Rd., Berwick, 3806*
[b] *Department of Chemistry, Monash University, Wellington Rd., Vic., Clayton, 3168*

## Abstract

An informal survey of a selection of industrial and government workplaces was conducted. The survey requested specific information on what employers considered important and relevant with respect to practical skills expected of a new chemistry graduate. In general, the employers did not have extreme expectations and it would seem that basic skills, familiarisation with a laboratory environment and some knowledge of common instrumentation are being reasonably well covered by typical undergraduate chemistry courses in Australia. Notably, employers indicated that the areas that needed greater attention were generic skills including: the ability to work in teams, communication skills including both written and oral, understanding of how a business operates, the ability to seek out information and critically assess it, an appreciation of the broader implications of chemistry in relation to an industrial process and interfaces with other disciplines, and some knowledge of statistics, data analysis and data presentation

## Introduction

The importance of doing practical work in undergraduate courses in chemistry has been discussed and debated in many arenas over many years. The aims of providing practical experiences in chemistry are many and may include:

1. to reinforce aspects of the theory component of the course
2. to provide training in selected practical skills, data collection and interpretation, report writing and presentation
3. to provide experience of designing experiments and the process of science
4. to give students "experience" of the laboratory environment, awareness of safety and ambience of this environment which has been so much a part of chemistry.

It has been argued that practical work may not be even be an essential part of all chemistry courses, particularly when the student is never intending to major in chemistry or work in a laboratory. However, the latter view overlooks the fact that the "laboratory experience" provides a useful vehicle for learning a variety of skills, which prepare the graduate for a professional career in wider employment settings.

University teachers are generally the chief influences on the content of undergraduate practical courses. The decision on the content of their laboratory courses is based on a number of principles:

1. Good ideas gleaned from other colleagues, universities and the literature
2. The practical content of their own undergraduate courses
3. Resource implications of practical exercises
4. What will fit into the allocated laboratory times
5. Relevance to the theory component of a course
6. Techniques needed for progression to the research laboratory
7. What is relevant to the "outside" world, that is, the skills and techniques required in industry

This paper presents the results of an informal survey of a selection of industrial and government workplaces, conducted in order to gather specific information on what employers considered important and relevant with respect to practical skills expected of a new chemistry graduate.

**Survey Instrument and Responses**

The survey attempted to cover a range of chemical industries, which included organisations involved in environmental and analytical chemistry, polymers, paint manufacture, cleaning agents, films and photographic supplies, the energy industry, power generation, farm chemicals and instrument manufacture. About 15 companies were contacted and interviewed by telephone or asked to respond by fax. The questions were addressed to the "chief chemist" or laboratory supervisor and these were people who generally had significant involvement in recruitment of new chemistry graduates.

The questions asked in the survey are listed below:

| | | | |
|---|---|---|---|
| 1 | For a graduate chemist who is going to work in a laboratory immediately after graduation, what skills do you expect in the following areas: | | |
| | (a) Practical? | (b) Occupational Health and Safety Knowledge? – specify if possible | (c) Interpersonal skills? |
| 2 | Would you place greater importance on any of these? | | |
| 3 | How much in-house training and induction is conducted by your organisation in the first year of a graduate chemist's employment? | | |
| 4 | What skills do the in-house programs focus on? | | |
| 5 | Is any of this out-sourced? | | |
| 6 | Are there other skills and knowledge expected of a graduate chemist coming into your industry, that you feel university courses are not covering well? | | |

A summary of the responses obtained follows:

***Comments on Practical Skills expected***

General

- Understanding of basic theory behind common instrumentation and ability to follow analytical methods (eg IR, GC, HPLC, AA)
- Using balances and weighing accurately
- Able to measure pH and understand the concept
- Able to make up solutions accurately and perform serial dilutions
- Good titration skills
- Knowledge of common glassware and its uses
- Not expecting a great deal but ability to learn quickly, follow instructions and seek advice if uncertain
- Knowledge of common sample preparation techniques

Occupational Health and Safety Knowledge

Most respondents indicated that this was extensively covered through in-house training. Some expectations that emerged were:

- General knowledge of safe conduct in the laboratory
- Disciplined adherence to company procedures
- How to use an Materials Safety Data Sheets
- Familiarity with Dangerous Goods storage regulations

Interpersonal Skills

This area was generally very highly rated by all employers

- Good communication (oral and written)
- Ability to work as part of a team
- Willingness to work and show initiative
- Ability to relate well to a broad group of people (eg other parts of the organisation, clients, other organisations)

***Importance Placed on Different Aspects of Practical Skills***

The majority of people interviewed indicated that they placed as much importance on inter-personal skills as they did on laboratory practical skills. Several respondents actually suggested these were more important when selecting candidates for a job and that deficiencies in practical skills could be overcome through further experience and training. In addition, deficiencies in OH&S knowledge were seen as an area that could also be overcome quickly by in-house training.
In general, from the expectations of employers, it would seem that basic manipulative skills, familiarisation with a laboratory environment and some knowledge (if not hands-on experience) of common instrumentation are being reasonably well covered by typical undergraduate courses in Australia.

*In-House Training*

The majority of the employers indicated that their organisation provided some form of induction program followed by further short courses relevant to the work the new graduate would take up. These programs were generally conducted by the organisation with little out-sourcing except for instances of special courses often linked to instrumentation or analytical methods. In most of the organisations, the new graduate worked closely with a senior mentor who taught them the specific skills and procedures required of the job.

The induction programs tended to deal with aspects of the organisation's structure and procedures, safety rules and lines of responsibility. The on-going training often dealt with further safety issues, improving interpersonal and communication skills and selected technical information sessions.

***Other Skills and Knowledge not covered well by Universities***

The most significant feature of the responses to this question was the similarity in feedback offered by all employers. It was suggested that Universities might put more emphasis on the following areas:

- Training and awareness of how a business operates
- Ability to work in teams over a long period of time
- Communication skills in general, including both written and oral
- An appreciation of the broader implications of chemistry in relation to an industrial process and interfaces with other disciplines
- Ability to seek out information and critically assess it.
- Some knowledge of statistics, data analysis and data presentation

**Discussion**

In 1997, the Faculty of Science at Monash University, conducted a survey of employers of science graduates where specific questions about generic skills were asked. In this survey, a questionnaire was sent to over 70 employers of science graduates around Australia. This survey was not specifically directed to chemistry graduates and addressed generic skills. However, the results were most interesting in that a similar message was received from employers.

The findings of the broader Faculty of Science survey reinforced the attitudes and expectations that emerged in our own survey of employers of graduate chemists. Team skills and adapting to a new environment were consistently rated as very important by a majority of respondents. The ability to communicate and relate to a cross-section of people was also rated very highly. Furthermore, these communication skills were extended to the written form including the ability to communicate scientific and technical information to a non-technical audience.

These findings are further supported by recent literature reports. In separate reports, Mabrouk (1998), Lawton (1997) and Chapman (1995) suggested that chemistry graduates in the UK and the USA are not prepared for the demands of industry. Both reports urge the incorporation of training in communication skills, teamwork and problem solving to cover areas in which graduates showed the greatest deficiencies. Similarly, Thorpe and Ullman (1996), point to the need for analytical chemists having a range of non-technical skills in order to pursue successful careers. The same skills are listed; good oral and written communication, ability to work with others, take initiative and manage ideas and information.

**Conclusion**

How can practical courses in chemistry address these additional needs as part of the broader university chemistry curriculum?

Cullen (1998), in his role as Head of the Federation of Australian Scientific and Technological Societies, recently identified a number of priority issues for Australian science. These included the need for science faculties to build closer links with industry and for generic science skills to be given greater prominence in science degrees. Many chemistry departments in Australian universities have course advisory bodies with significant industry representation. Less common, but increasingly, generic skills are being given greater prominence through revamping existing subjects or the introduction of new ones.

In the laboratory context, greater emphasis can be placed on communication, teamwork and reporting skills. Garratt(1997) has suggested a number of strategies, which encourage students to think as a professional chemist including developing experimental design and data interpretation skills in the laboratory. Johnstone (1997) advocates the need for proper preparation before students undertake laboratory work and this will include planning and critical thinking skills. Overton (1997) has suggested the use of logic problems to encourage critical thinking, logical reasoning and deduction. An extension of this could be incorporated into the laboratory where students undertake some practical activities where a problem or riddle is to be solved, rather than the more typical "recipe" style of exercise followed by interpretation of the results.

Practical work in chemistry provides considerable opportunities to address the additional skills that employers are asking of our chemistry graduates. A greater emphasis on some of these skills can be achieved with some thought to how we design our practical exercises.

**Acknowledgement**

Many thanks to Mrs. Sandra McNamara (Faculty of Science, marketing and publicity officer) who supplied the information on the generic skills survey conducted by the Faculty of Science at Monash University

**References**

Chapman, S. 1995, "Educational standards, educational reform, and CPT" *Chemical and Engineering News*, 73, 49
Cullen, P. 1998, quoted in "FASTS News", *Chemistry in Australia*, 65 (3), 27
Garratt, J. 1997, "Virtual Investigations: ways to accelerate experience", *University Chemistry Education*, 1(1), 19-27
Johnstone, A.H. 1997, "...And some fell on good ground", *University Chemistry Education*, 1(1), 8-13
Lawton, G. 1997, "Business skills for boffins", *Chemistry and Industry*, 19, 752
Mabrouk, P.A. 1997, "Shaping America's scientific and technological workforce", *Journal of Chemical Education*, 75 (5), 527-529
Overton, T.L. 1997, "Creating critical chemists", *University Chemistry Education*, 1(1), 28-30
Thorpe, T.M., and Ullman, A.H. 1996, "Preparing analytical chemists for industry", *Analytical Chemistry*, 68, 477A-480A

# CONSTRUCTING A COMPUTER ASSISTED LEARNING ENVIRONMENT FOR CHEMICAL EDUCATION IN SCHOOLS: CONVERSATIONS BETWEEN ENGINEERS AND A CHEMICAL EDUCATOR

**Susan Rodrigues**

*University of Melbourne, Parkville, Victoria, 3052*

## Abstract

Intentional application of research on cognition to the design of software is frequently absent and at best, unsystematic (Hannafin and Rieber, 1989). There is an impression that software engineers are sliding into an ad hoc approach which is not underpinned by learning theories. More recently, software is being touted as constructivist, primarily because access to information is non linear and offers scope for personal or communal interaction. This paper describes the difficulty in translating educational research influences into software design by reporting on conversations between engineers and a chemical educator in preparing a CDROM on atomic structure aimed at year 9 students.

## Introduction

There is an assumption that instructional design system (ISD) is influenced by educational research and in particular, views of learning. Hannafin and Rieber, (1989) contend that when learning theory, albeit unacknowledged, does influence ISD, it is a consequence of psychology paradigms of the time. For example, early systems were developed in line with behaviourist ideology. Current systems, by promoting the notion of non-linear access choice, are implying an inclination toward constructivist philosophy. Indeed, even though Streibel (1989) suggested that constructivist assumptions and ISD methods are not compatible and Jonassen (1991) suggested that ISD methods need to modify their theory base to take on board constructivist principles, burgeoning technology involving hyperlinks and open pathway access assumes constructivist influences. Yet a text book is not considered constructivist, even though it allows an open pathway access, flit from page to page, and it links pages through keywords and the index.

For educational researchers, the differences between the constructivist and behaviourist schools of thought are much wider. ISD influenced by behaviourist ideology would segment key concepts to build a bigger picture while constructivist influenced ISD would warrant realistic contexts, scaffolding, and metacognitive tasks through which students will develop their understanding. A behaviourist influenced tutoring and assessment computer assisted learning environment tries to quantify learning in some way. Whereas extreme constructivist philosophy often supports a view of qualitative change in personal understanding to be a real test, yet one that is not measurable at that instance in time (Cunningham 1991). Yet another difference lies in the notion of motivation. A behaviourist ISD has extrinsic goals, a constructivist approach emphasises metacognition and an intrinsic notion of success. Indeed behaviourist tutorials involving repeat practice, reinforcement and control are opposite to goals advocated by constructivist philosophies (Heinich, 1984), where the notions of reflection, active construction and, personal relevance and autonomy (Lebow, 1993) are considered crucial facets of constructivist learning. According to Dick (1991) this issue of differences in perspective and seemingly incompatible contradictory stances can be addressed on two fronts. The software could be influenced by constructivist ideology or the technology may be employed as a tool in situated practice within a constructivist classroom.

This paper reports on a collaborative venture between researchers and engineers in producing software, on atomic structure and the Periodic Table, that is guided by constructivist philosophy and research findings from a project (Rodrigues and Wong, 1997). The project investigated year 9 students' use of a CDROM advertised as being constructivist influenced. This paper illustrates some of the difficulties encountered in interpreting and accommodating constructivist philosophies, in what are often considered objectivist environments, and highlights some difficulties that arise in attempting to merge ISD with constructivist philosophy.

**Experiment**

This paper fits into the action research paradigm (Carr and Kemmis, 1986). It reports on an investigation into particular ideas in practice as a way of improving and increasing our knowledge of the curriculum, and it involves collaboration. It is not attempting to identify causal laws. It is drawing on experience and research to illuminate a single situation within the context of a more global perspective.

Groups of final year student engineers are expected to work with clients on realistic tasks as part of the University of Melbourne's Computer Software Engineering Course. A chemical education researcher, with a familiarity of constructivist philosophy, became a client. The conscientious engineers were asked to create a Computer Aided Learning Environment (CALE) that could be used to support Year 9/ 10 students learning about atomic structure and the periodic table. Four software engineers were monitored during the year long process. The engineers prior ideas with respect to learning were identified and experiences were provided to help familiarise the engineers with constructivist philosophy. Meetings were audiotaped, email messages collected and access to work in progress was noted through a web site managed by the engineers. The engineers provided access to minutes from engineers -only meetings and provided hard copies of documentation related to task accomplishments. The engineers also completed an emailed questionnaire that sought to identify their views of teaching and learning. To ensure some degree of validity, transcripts, other data and interpretations were made available to the engineers for comment.

The heterogeneity of the group, educational researchers and engineers, in terms of previous experiences and roles in the group, no doubt resulted in group members complicated allegiances and different discourses. The perception of what were 'critical' issues and what were 'fundamental' assumptions is determined by our view of the world and this perception. This paper describes some of those issues and assumptions and illustrates how they influence the construction of software.

## Some Findings

Transferring research findings into software reality relies on educational researchers and engineers being able to share in their interpretation of research findings and being able to communicate ideas. Incorporating constructivist ideology into software design is difficult for two main reasons:

a) interpretation and shared understanding of terms and goals

b) limits with respect to the technology.

With respect to goals, notions of appearance, non-linear access, motivation and interactiveness were initial foci of talks between the researcher and engineers and were taken on board by the engineers during early stages of the project :

"Hopefully, this CALE will provide information to students in such away that they find it interesting and thus will remember the concepts taught. For example when a kid watches a great movie that is really exciting they can come to school the next day and quote parts of the film. If we can produce some software that is so exciting that they will remember it with out even trying this will be success. (1.- email)

" The aim of the CALE that we are trying to construct is to assist students to develop their understanding of introductory Chemistry concepts. The CALE is to be non-linear and facilitate student-centred exploration of the relevant material ie. the students can examine the material in any order and at their own pace. Ultimately we are trying to supplement what the students learn in their Chemistry/Science classes." (2. - email)

"It will allow students to progress at their own pace, learn what they want to learn, instead of being forced along a particular path. The other CALE's that I have encountered have forced the student to progress along a linear path." (3.-email)

"I would imagine the aim is to provide an experience that a book cannot. Perhaps a computer assisted learning environment may some day replace a human instructor, though I doubt it, but the CALE that WE are endeavouring to create is intended to provide functionality that a book cannot." (4. - email)

Aesthetics, non-linear, quality graphics, open access choice and self directed pace, were all viable and are clearly visible in the final product.

The notion of knowledge being an individual's construct was initially alien to the engineers. However even though the term became more familiar to them its interpretation and transference was more difficult. Constructivist came to mean construction. Providing students with opportunities to manipulate, build, and construct 'atoms' was perceived to be constructivist. Hence the notion of hands on interactivity was perceived to be addressing the construction of knowledge remit.

One engineer suggested that the technology itself curtailed the notion of minds on interaction in terms of metacognitive skills and fostering self-questioning. Building in effective engagement, or scaffolding, and cueing for active engagement was hard to achieve because this required control of cognitive overload, while still providing good navigation through the software and providing immediate goals. An effective teacher manages all three.

The engineers tried to incorporate metacognitive devices such as advance organisers and frequent decision points while trying not to induce cognitive overload. They considered including anchors for the concepts, by including relevant everyday contexts, and they sought to provide help facilities and advice statements in the software. Assumed common understandings were soon seen to have different meanings. There were challenges in terms of negotiating meaning, from a technology frame of reference and from an educational frame of reference. This jostling for meaning within the discussion can be seen in the following excerpt where one scaffolding device the 'help' context was discussed. The engineers perceived 'help' to minimise cognitive overload while maintaining learner control of navigation. The educational researcher perceived help as a concept facilitator facet in the software.

A test version of the preliminary screens shown in Figure 1 was provided on the Internet and these screens are discussed in the transcript.

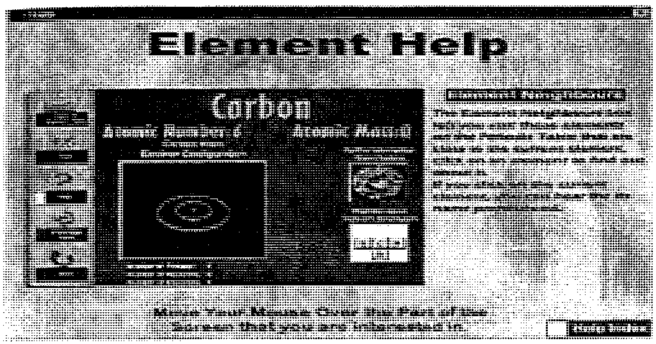



Figure 1 Screen showing carbon as example

| | Verbatim transcript | Researcher's comment |
|---|---|---|
| R | Is it going to be about atomic mass or is it going to be about..... | Clarification required about 'help' button. |
| D | No! It'll be about using that screen. | His perspective is different to either 'help' as a means of scaffolding a particular concept or 'help' to understand various icons. |
| J | Using that particular screen. | Hence 'help' is about navigating around a particular screen. A view shared by two of the engineers. |
| R | This is isn't about using this 'help' screen, isn't about using the screen it's about context? | Clarifying that it is the page. |
| M | No, no. | |
| J | Hang on. I'll give you, give you an example, OK? You've got your lithium screen. Now what this bit here will contain is a shrunken version of the actual screen which you just came from. As an example. With arrows and little arrows and diagrams saying press this button to do this. Press this button to do this, press this button to do this. | A small scale version of the same element page will be on the help screen. It will have 'live' components that provide details about the screen. |

Help became a means of helping students through the software, a means of familiarising them with the different active and linked aspects of various screens. It did not provide any scaffolding in terms of helping them clarify concepts, ideas or beliefs. Stipulating requirements in contracts did not result in common interpretation. The transcript on 'help' highlights this interpretive process, even though the Software Requirement Specification stated requirements of the product, for example the inclusion of a help button. Interpreting these requirements was achieved, where possible, through constant discussion. 'Help', 'construction', 'scaffold', were all interpreted in a hands on manner by the engineers. The researcher's idea of 'minds on' constructing knowledge was manifested as an engineers 'hands on' constructing of objects. Building atoms, altering the number of protons and electrons, was interpreted as having reached the constructivist idea. This is constructionist, rather than constructivist.

Other difficulties in translating research findings into reality stem from limitations with current technology. Making software non-linear by building in hyperlinks does not make it constructivist, thought it may make it less behaviourist. Users can still proceed from screen to screen without an reflective thought. Furthermore, the decision to go from screen F to screen A, may have involved little or no conscious thought.

The role of language, a crucial aspect of constructivist tenets, is not easily transferred into technological applications. The artificial intelligence necessary to interpret submitted responses in not widely available. If the software is designed to allow for navigation ease, students could respond to questions by accessing appropriate screens, rather than developing any understanding for a particular concept. For example, faced with a question pertaining to the atomic mass of carbon, the student could simply go to the screen of carbon and read the value on the screen. This does not mean the student understands how the concept of atomic mass is deduced. However, to include scaffolds/help, that are a natural practice with effective teachers, creates difficulties in the technology with respect to cognitive overload and circumnavigation. To try to circumvent this, the nature of questions in a CALE has to change. This has begun to be addressed. Most CALEs can accommodate 'what?' questions, but not 'why?' nor 'how?' questions, and this is one of the fundamental differences between behaviourist and Constructivist views of learning. Both views are concerned with the learner demonstrating an awareness of scientific community accepted ideas, Constructivists are also interested in whether the learner understands how and why this response is considered acceptable.

## Discussion

If the emphasis of ISD is on processing knowledge rather than how we learn, then instructional systems that create hyperlinked multimedia textbooks are still underpinned by behaviourist rather than constructivist views of learning. Constructivist research findings in terms of non-linear access, context, autonomy, relatedness, self regulation, and active engagement in the learning process have to be interpreted and translated into software design. With current technology non-linear access and to some degree, autonomy and self regulation, can be translated into software design.

However, designing software that allows the user access to screens at their own discretion, without encouraging the user to actively construct meaning or reflect on their constructions, will not lead to active engagement or metacognition. ISD has to do more than provide functionalist transmission of information bytes in a non linear fashion if it is to be considered constructivist.

The notions of metacognitive devices such as advance organisers, anchoring the concepts, providing help facilities and advice statements, as well as frequent decision points without inducing cognitive overload or making navigation difficult are fundamental constructivist concerns in the development of software. The influence of constructivism on multimedia software design will be a consequence of the still-emerging technology, and even though negotiation of meaning between behaviourist influenced software engineers and constructivist influenced educational researchers has begun, current limitations of technology and artificial intelligence continue to limit constructivist influence.

To a certain degree, the move from what were perceived to be behaviourist underpinned tutorial systems has been replaced by ISD that promotes user access choice. However, this is more than likely due to advancement in the technologies themselves. Perhaps, particular facets of technology, such as hyperlinks, have become more prominent in the 1990's and hence the software design reflects new potential, rather than an awareness and interpretation of constructivist philosophy. How can we expect software engineers to design software in line with constructivist paradigms if newly qualified engineers have not been versed in these ideas. Expecting engineering courses to include learning theory is probably unrealistic. This means that communication between the researcher and the engineers needs to involve more than a contract and the construction of an software requirement specification document. Certainly, from this small study involving conscientious software engineers and a zealous chemical education researcher, there were differences in terms of shared understanding of constructivist terms and goals which were brought about by an existing unconscious intuitive view of learning and limits with respect to the technology. Therefore, perhaps, at the moment, because it is difficult for the software to be significantly influenced by constructivist ideology, we should settle for employing technology as a tool in situated practice within a constructivist learning environment.

## References


Carr, W. and Kemmis, S. (1986). Becoming critical: Education, Knowledge and Action Research. London. Falmer Press.

Cunningham, D. J. (1991). Assessing constructions and constructing assessments: a dialogue. *Educational Technology* XXX1, 13 -17

Dick, W. (1991). An instructional engineers view of constructivism. Educational Technology, 5, 41 -44

Hannafin, M.J and Rieber, L. P. (1989). Psychological foundations of instructional design for emerging computer based technologies, *Educational Technology Research and Development*, 37, 91 -101

Heinich, R. (1984). The proper study of instructional technology. *Educational Communication and Technology Journal*, 32 (2), 67-87

Jonassen, D. (1991). Objectivism versus constructivism: Do we need a new philosophical paradigm? . *Educational Technology Research and Development*, 39(3), 5-14

Lebow, D. (1993). Constructivist values for instructional systems Design: Five principles toward a new mindset *Educational Technology Research and Development* , 41(3), 4-16

Rodrigues, S and Wong, N (1997). *Effects of Teaching and Learning atomic structure concepts through the use of constructivist influenced Multimedia.* Preprint Number 2/97. Department of Science and Mathematics Education. University of Melbourne.

Streibel, M (1989). *Instructional plans and situated learning. The challenge of Suchmans' theory of situated action for instructional engineers and instructional systems*. Dallas, TX Association for Educational Communications and Technology. .

# PRIMARY TO SECONDARY: THE FORGOTTEN GAP

**Keith Skamp**

*Southern Cross University, Lismore Campus, PO Box 157, Lismore, NSW 2480.*

**Abstract**

Primary school students are capable of learning chemistry. Should the focus at this level be on the macroscopic, the microscopic or the symbolic? Two classes in a Queensland primary school were taught about atoms and molecules: Year 5 and 7. Data obtained by using the Australian Council for Educational Research's (ACER's) *Tapping Students' Science Beliefs*, and interviews with students and teachers, both before and following an instructional sequence, suggest that many primary students appear to appreciate aspects of the particulate nature of matter (the 'microscopic'). Further they seem to really enjoy the learning experiences, many of which focussed on the use of molecular models. This paper reports the effects of the lesson sequences and raises questions about the implications for the primary curriculum.

## Introduction: A Place for Chemistry at the Primary Level

Just as there is a need to explore the gap between the secondary and tertiary chemistry curriculum because there is sometimes a weak connection between them (Jong, Schmidt & Zoller 1998) consideration needs to be given to primary school chemistry (Skamp 1996) and its links to the secondary school curriculum. When considering this issue it is useful to see chemistry education at three levels of explanation: sensory; atomic/molecular (microscopic or particulate); and symbolic (Gabel, Samuel & Hunn 1987) and to ask should particulate chemistry be part of the primary curriculum?

The Australian Science Curriculum Profile (AEC 1994) includes the particulate nature of matter in the upper primary curriculum, as do other country's curricula (Davies et al. 1996). Many primary texts assume particulate understandings (Lee, Eichinger, Anderson, Berkeimer & Blakeslee 1993). However research (e.g. Andersson 1990; Adams, Doig & Rosier 1991; Krnel, Watson & Glazar 1998) indicates primary students do not intuitively hold or use particulate conceptions to explain chemical phenomena, and even find difficulty after instruction (Children's Learning in Science Project in Andersson 1990; Gabel & Bunce 1995; Novick & Nussbaum 1978). In contrast Novak and Musonda (1991) and Lee et al.'s (1993) studies suggest that upper primary students (maybe 50%) could appreciate microscopic level studies; hence the issue remains problematic.

## Atoms and Molecules: A Direct Teaching Sequence

Leisten (1995, and references therein) has argued that primary age students can appreciate that the world comprises atoms and molecules and that they are arranged and move in different ways, depending upon the states of matter; further their molecular weights can help to explain various properties. His two lesson sequences (phases 1 and 2) comprising about eight hours of teaching over the last two years of primary school have been trialed in a small number of British primary schools. The emphasis is "on (molecular) model making" and the "fun of predicting molecules" with "chemical puzzles" in phase 2 (interview August, 1997). They also include video, an apparent emphasis on the correct use of words, as well as role play- these are strategies advocated to clarify conceptions by Garnett, Garnett, & Hackling (1995) although they would probably argue that the problem solving tasks are the rote application of concepts and algorithms, which may hinder conceptual learning. Leisten's ideas have caused considerable debate (Davies et al. 1996).

## Research Methods

Evidence for the success of Leisten's lessons is anecdotal. Hence this study focuses around the two main research questions: Firstly, can middle and upper primary students use a Particulate Model of Matter to explain physical and chemical phenomena *after* experiencing Leisten's Phase 1 and 2 sequences? If ideas have changed what appears to be the main factor(s) effecting the change? Secondly, what do these students and their teachers think about these lessons?

Changes in the students' conceptual understanding of the particulate nature of matter were ascertained using the ACER's (Adams et al. 1991) *Tapping Students' Science Beliefs* Instrument (TSSBI). This is a paper and pencil instrument which determines the "underlying conceptions" (rather than learnt algorithms) which learners hold about the 'Structure of Matter'. It takes "students through the steps involved in making pancakes, asking them to comment on, and explain, the observations of characters in the story by providing illustrated and written responses" to nine items (Adams et al. p. 9). The tasks "explore whether students would spontaneously use the particulate model to describe the structure of matter" (p. 12) and related phenomena such as changes of state and dissolution. Responses to items can be categorised into mutually exclusive categories (e.g., see Table 1), and summed to determine whether students were at prescientific, developing scientific, and scientific conceptual levels (Doig and Rosier 1993), as well as sublevels (Adams et al. 1991).

Two classes, Years 5 and 7, in a provincial Queensland primary school were taught the phase 1 and 2 lesson sequences respectively during 1997. The Year 7 class had experienced the phase 1 sequence in 1996. Responses to the TSSBI were obtained for both groups prior to and at the completion of the sequences. Hence the delayed learning effects from the phase 1 sequence (for Year 7) and the immediate effects of phase 1 (Year 5) and phase 2 (Year 7) were determined. A selection of responses which were more difficult to interpret and/or showed considerable changes were followed up by interviews on both occasions (pre: n=10, Year 5; n=15, Year 7; post: n=15, Year 5; n=13, Year 7). Interview responses were used to determine final item levels for further analysis. In the post interviews the students were asked from where did they get their ideas and, if they referred to the lessons, follow-up-questions were used to determine if the students enjoyed the lessons and why, what they learnt, whether they had used the ideas elsewhere and if they had changed the way they think about their world. To obtain a more complete picture of the sequences and their effects, Leisten and the teachers were interviewed pre and/or post the sequences. Teacher diaries and lesson notes were studied.

## Results

The percentages of students at prescientific, developing scientific, and scientific conceptual levels were determined, as well as at the sublevels of these categories. Prior to instruction Year 5 students all used conceptions dominated by the directly observable and could be classified as "pre-scientific" in their thinking (Doig & Adams 1993, p.57) while 11 percent of Year 7 students were initially at a "developing scientific" level. After instruction the proportion of both groups at this level was about 25 percent. These changes were significant (0.001 level, chi square) only for the Year 5 group. When individual conceptual level changes were compared over 70 percent of Year 5 students moved up levels compared to 40 percent of Year 7 (with about 20 percent of the latter group falling).

Approximate comparisons with Victorian TSSBI results (Adams et al. 1991) suggest the distribution of post Year 5 and 7 students at the ends of the developmental continuum are similar for all three groups. This is despite the fact that post instruction far more Years 5 and 7 students gave particulate responses to those items directly related to the lessons. This could mean that most of the movement occurred in the middle of the developmental continuum.

There were obvious pre-post changes towards particulate thinking on individual lesson specific items, viz., structure of a solid, nature of matter and changes of state. For the first two, differences were significant (chi square, 0.05 or less) for both groups, but only Year 5 for the last mentioned. Apart from significant changes for evaporation (Year 5) and 'What's in a bubble?' (negative, Year 7) there were no other significant changes. The lessons made no reference to condensation, dissolution or chemical reactions, and the vast majority of students were unable to extrapolate their awareness of atoms and molecules to the four items related to these phenomena.

When the Year 7 post instruction results are compared with the year 5 post responses significantly more Year 5 students were using the particulate model for the structure of a solid and change of state. It was only Year 7 which showed relatively small but obviously forward chi square significant differences, related to items not associated with the content of the lessons. Responses for states of matter, dissolution, condensation, and evaporation did not significantly depend on the year levels.

Table 1
*Percent of Year 5 and Year 7 Students (Pre and Post Instruction) at Different Conceptual Levels on selected items[1] on the ACER (1991) Particulate Nature of Matter TSSBI (compared with Victorian Sample)* (Adams et al. 1991)[2]

| Item and Conceptual Level | Year 5 Pre (n=48) | Year 5 Post (n=47) | Year 7 Pre (n=46) | Year 7 Post (n=45) | Victorian (n=538) |
|---|---|---|---|---|---|
| 1. Structure of a solid | | | | | |
| Particulate (1) | 0 | 66 | 4 | 22 | 11 |
| Continuous (0) | 98 | 34 | 94 | 78 | 75 |
| 2. Structure of matter | | | | | |
| Particulate (4) | 2 | 60 | 20 | 64 | 1 |
| Continuous (3) | 25 | 19 | 28 | 20 | 57 |
| Properties (2) | 27 | 2 | 11 | 2 | 3 |
| Examples (1) | 31 | 17 | 39 | 13 | 33 |
| 3. Dissolution | | | | | |
| Suspended (2) | 4 | 6 | 4 | 9 | 0 |
| Invisible (1) | 19 | 28 | 22 | 22 | 12 |
| Mixes in/disappears (0) | 75 | 60 | 74 | 67 | 44 |
| 4. Change of state | | | | | |
| Particulate (3) | 0 | 9 | 9 | 18 | 1 |
| Particulate (incomplete) (2) | 0 | 51 | 15 | 24 | 4 |
| Heat and State (1) | 67 | 23 | 48 | 22 | 43 |
| Restatement (0) | 33 | 15 | 26 | 36 | 0 |

1. The other items were condensation, conservation of matter (burning), what's in a bubble? (gas expansion), cooking (chemical change), and evaporation.
2. Percentages do not add to 100% as some Year 5 and Year 7 students did not respond to some items; in the Victorian sample uninterpretable responses are not included.

Interestingly the Year 7 students did not, in general, differ significantly in their specific item pre-conceptual level distributions to the pre Year 5 group. Further it does seem that the post Year 5 student results for the structure of a solid, states of matter, and changes of state are proportionately at higher levels than the pre Year 7 results. The older students in their post results, do not "catch up" on the structure of a solid item, but do so for the states of matter, and some perform marginally better on the change of states item (although when partial particulate responses (level 2) are considered, this is not the case). (On the dissolution, condensation, what's in a bubble (top two levels) and evaporation (top level only) items there were no post Year 5-pre Year 7 differences, and this remained the same when compared to the post Year 7 data, except that the post-Year 5 students performed better than the post Year 7 results on the 'what's in a bubble' item. Only on the cooking and burning items did the pre-Year 7 students outperform the post Year 5 students and maintain or slightly improve that difference in the post results.)

Analyses of the interviews indicated that some of these students' macroscopic conceptions about chemical and physical phenomena (e.g., dissolution and burning) were similar to the literature, although condensation was an exception, but these interviews also noted that obvious evidence of reported alternative atomic/molecular conceptions, such as atoms taking on the shape of macroscopic objects, could only be found in a few instances (see e.g., Andersson 1990). Many of these students held scientific views about, for example, the movement of molecules.

Comparison of the Year 7 interview responses with Year 5 suggests that the younger interviewees responded with as many meaningful ideas as Year 7. All believed they had learnt about atoms and molecules often mentioning the model building blocks. The Year 5 students recalled more specific molecular details. The behaviour of molecules, especially the change of state of water, was consistently referred to, even by Year 7 after a period of many months, whereas the concepts of 'joining power' and molecular weight were rarely mentioned. All students said they had enjoyed the lessons as they were fun, active and involved new content. When asked if the phase 1 lessons affected the way they viewed their world most said they now saw everything as made of atoms and molecules. Very few had used the ideas elsewhere.

The teachers thought the lesson sequences were "very positive" and focussed on things that "are made of littler bits and littler bits"... "rather than ... formulae". None considered them too abstract but rather spoke about their "concrete" nature. As evidence of effective learning good mini-test results, question answers, and students electing to do more work in the area, were mentioned. Heather was most enthused about teaching these lessons and would reteach the sequence because of the "positive [student] feedback".

## Discussion

The movement between prescientific, developing scientific and scientific conceptual levels indicates the Year 5 students did advance their conceptual level over the instruction period, with more being able to explain phenomena without reference to the directly observable. About 10 percent of the pre-Year 7 students were already at similar levels perhaps implying a similar (and sustained) impact from the phase 1 sequence, but overall conceptual level changes were more limited for this group. Post instruction similar numbers of Years 5 and 7 students were at the three levels. These results suggest that the phase 2 sequence may not be as conceptually effective. This may be due to it being less pedantic about basic particulate model attributes (Ahtee and Varjola 1998) or maybe as one teacher commented: the Year 5 were "a bright little lot", more motivated and with relatively higher reading scores than the Year 7 group.

Initial consideration of the conceptual levels for the specific items appears to support the above interpretation, but closer analysis may suggest an alternative view. Comparison of the Year 5 pre and post specific item results suggests that conceptual understanding is more effective for those items most recently studied (structure of a solid, states of matter and change of state). With the Year 7 students many may have reverted to previously held conceptions to respond to the pre-questions.

Revision of phase 1 content in phase 2 probably explains the post Year 7 results on two of these items. The conceptual level distributions for most of the other items do not seem to significantly depend on the year level suggesting that neither of the lesson sequences encourage most students to extrapolate their particulate understanding to non-studied phenomena. With the burning and the cooking items some older students may be starting to move towards a higher conceptual level.

Comparisons with the Victorian sample, who probably have not experienced similar lessons (Rosier & Symington 1990), again suggest that the Leisten lesson sequences have been effective in advancing conceptual levels relating to lesson specific items. However that the pre Year 7 scores are similar to the Victorian sample suggests that learning may be superficial (memorisation?). However this may be too critical an interpretation of the results. The revised Matter and Molecules (MAM) sequence (Lee et al. 1993) with Year 6 students in the USA involved 35 lessons, with teachers specifically concentrating on previously identified misconceptions. Comparison of the percentage of MAM students achieving "adequate understanding" (p. 260) of molecular goal conceptions and those Year 5 and 7 students responding at particulate levels on lesson specific items indicates that the Queensland students achieved at least as well as the MAM group.

Overall these across time changes and between year level differences, or lack of them, and comparisons with other studies, may indicate that some effective conceptual level change towards a particulate understanding is occurring in relation to specific contexts studied in the Leisten sequence. The pre Year 7 data though could mean that the learning may only be short term for most items. However the post interview data provides strong evidence that attempts to use atomic/ molecular explanations increased for most items and some Year 5 and more Year 7 students do offer credible particulate responses and this suggests that primary teachers could carefully introduce particulate explanations. Despite these cautious comments it cannot be denied that the vast majority of these students enjoyed these lessons and most felt they had changed their views about the world.

In response to the first research question there are understanding gains (possibly short term) with significant improvements in conceptual levels post instruction on lesson specific items. This seems to be more so with the first sequence. If similar criteria were used as in the MAM study the conclusion that "middle (here read upper primary) school students are capable of understanding some important aspects of the kinetic molecular theory" (Lee at al. 1993, p. 268) would be supported. The extent to which this understanding is retained however is problematic.

With reference to the second research question these students looked forward to the lessons and enjoyed the teaching strategies especially using the models to solve problems. All four teachers strongly agreed about the apparent strong attitudinal impact of the lessons. Leisten may be correct about the espoused attitudinal benefits of teaching "atoms and molecules". As attitudes towards science probably develop by the end of primary school (Harlen 1985) lessons such as these may make an important affective contribution.

Should atoms and molecules be taught to primary students? From this study the answer is probably a strongly qualified "yes". If Leisten's approaches were used together with those suggested by others (Gabel, Briner & Haines 1992; Garnett et al. 1995; Lee et al. 1993) the sequences may result in better longer term understanding. This view is taken because these upper primary students seemed so keen to learn about atoms and molecules and as affective considerations are thought to strongly influence cognitive learning (Fensham 1988) foundations for later learning may be possible.


## Acknowledgments

The receipt of an ARC Small Grant assisted the completion of this project. Further the willingness of the school, the four teachers and their students (as well as Emeritus Professor Leisten) to be involved is gratefully acknowledged as is Ms. Diane Newton's work as a research assistant.


## References


Adams, R., Doig, B., & Rosier, M. 1991, *Science Learning in Victorian Schools: 1990*, Australian Council for Educational Research (ACER), Hawthorn.

Ahtee, M. Varjola, I. 1998, 'Students' understanding of chemical reaction', *International Journal of Science Education,* vol. 20, no. 3, pp. 305-316.

Andersson, B. 1990, 'Pupils' conceptions of matter and its transformations (age 12-16)', *Studies in Science Education,* vol. 18, 53-85.

Australian Education Council 1994, *Science- A Curriculum Profile for Australian Schools,* Curriculum Corporation, Carlton.

Davies, M., Gillespie, R., Hogue, L, Leisten, J., Potts, C., & Skamp, K. 1996, 'Can and should 'real' chemistry be taught to elementary students?' in *Proceedings of the 14th International Conference of Chemical Education*, ed. W. Beasley, University of Queensland, Brisbane, pp. 192-194.

Doig, B. & Rosier, A. 1993, *Tapping students' science beliefs*, ACER, Hawthorn.

Fensham, P. 1998, 'Familiar but different: some dilemmas and new directions in science education', in *Development and Dilemmas in Science Education,* ed. P. J. Fensham, Falmer, London, pp. 1-26.

Gabel, D. & Bunce, D. 1995, 'Research on problem solving: Chemistry in *Handbook of Research on Science Teaching and Learning,* ed. Gabel, D., Macmillan, New York, pp. 301-326.

Gabel, D., Briner, D., & Haines, D. 1992, 'Modelling with magnets', *The Science Teacher*, vol. 59, no. 3, pp. 58-63.

Gabel, D. L., Samuel, K. V., & Hunn, D. 1987, 'Understanding the particulate nature of matter', *Journal of Chemical Education,* vol. 64, no. 8, pp. 695-697.

Garnett, P., Garnett, P., & Hacking, M. 1995, 'Students' alternative conceptions in chemistry: A review of research and implications for teaching and learning', *Studies in Science Education*, vol. 25, pp. 69-95.

Harlen, W. 1985, *Teaching and Learning Primary Science*, Harper & Row, London.

Jong, O., Schmidt, H., & and Zoller, U. 1998, 'Guest editorial: Chemical education in Europe', *International Journal of Science education*, vol. 20, n. 3, pp. 253-256.

Krnel, D., Watson, R. & Glazar, A. 1998, 'Survey of research related to the development of the concept of 'matter'', *International Journal of Science Education,* vol. 20, no. 3, pp. 257-289.

Lee, O., Eichinger, D., Anderson,, C., Berkeimer, G., & Blakeslee, T. 1993, 'Changing middle school students' conceptions of matter and molecules', *Journal of research in Science Teaching,* vol. 30, no. 3, pp. 249-270.

Leisten, J. 1995, 'Teach atoms earlier!', *School Science Review,* vol. 77, no. 279, pp. 23-27.

Novak, J. & Musonda, D. 1991, 'A twelve year longitudinal study of science concept learning', *American Educational Research Journal*, vol. 28, pp. 117-153.

Novick, S., & Nussbaum, J. 1978, 'Pupils' understanding of the particulate nature of matter: A cross age study,' *Science Education,* vol. 65, no. 2, pp. 187-196.

Rosier, M. & Symington, D. 1990, 'What Year 5 teachers say they teach', *Investigating: Australian Primary Science Journal*, vol. 6, no. 2, pp. 10-12.

Skamp, K. 1996, 'Chemistry in the elementary school: Has its potential been realised?', *School Science and Mathematics,* vol. 96, no. 5, pp. 247-254.

# BRIDGING THE GAP BETWEEN THEORY AND PRACTICE

**R. J. Sleet**

*Department of Chemistry, Materials and Forensic Science, University of Technology, Sydney.*

**Abstract**

This paper considers two mental functions: perception and the storage of knowledge in long-term memory. These two processes are important functions in information processing models of learning. Explanations are given in this paper of practices which are designed to enhance the effectiveness of these two functions. The practices are based on the findings from research in education and neural science. They include the use of readiness packages, creativity exercises, challenging thinking tasks, whole brain learning and the practice of giving immediate feedback.

**Introduction**

A model of learning derived from knowledge of the ways the human brain processes information is shown in Figure 1. This paper will focus on two important functions designated in the model, namely perception and the storage of knowledge in long-term memory. The purpose of this paper is to explain practices which are designed to improve the quality of learning outcomes in chemistry by enhancing the effectiveness of these two functions.

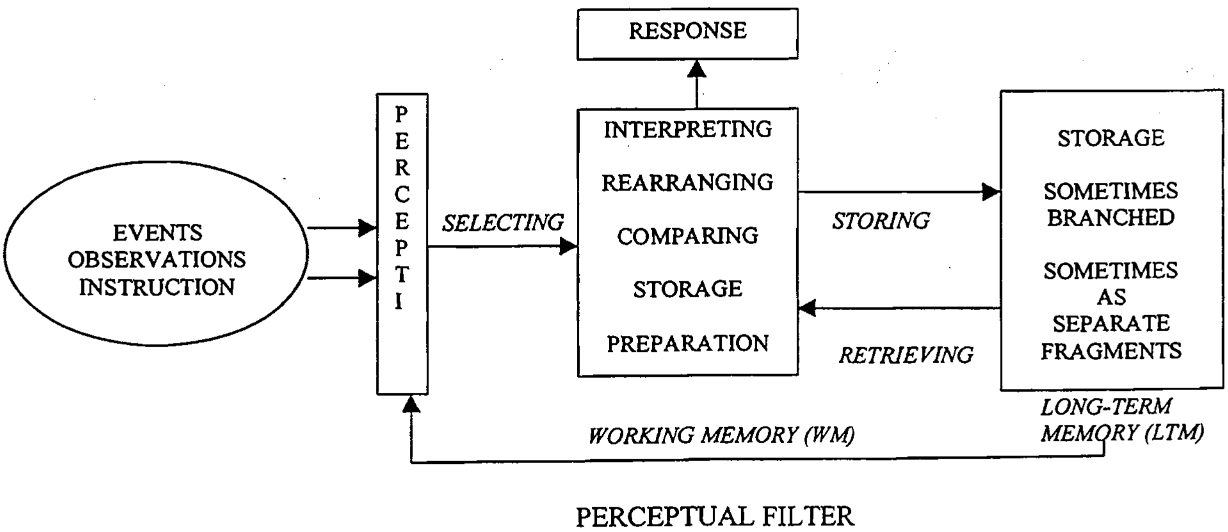



**Figure 1** **An Information Processing Model of Learning (Adapted from Johnstone, Sleet and Vianna (1994))**

## Perception

Perception is the way we interpret what we sense in our environment. This paper will be concerned with visual and auditory perception; that is it will consider what influences the way our brain interprets what we see or hear. Factors which influence perception are listed in the second column in Figure 2. In order to enhance students' abilities to perceive a new learning experience effectively the first two factors in this list (students' study processes and their prior knowledge) should be considered before the students undertake the new learning experience. This stage is referred to as the pre-stage in perception. The last two factors in the list in Figure 2 shown as influencing perception (students' misconceptions and their attention spans) should be considered when the student is undertaking a new learning experience. This stage will be referred to as the sensing stage in perception. These two stages will be considered separately.

### Pre-stage in Perception

Studies of student learning have identified two different approaches to learning called deep and surface learning. According to Ramsden (1992), students who adopt a deep approach to learning try to understand new knowledge, try to relate it to previous experiences and to everyday life and attempt to "organise and structure content into a coherent whole". On the other hand, Ramsden (1992) explains that students who adopt a surface approach merely aim to "memorise information for assessments", they "associate facts and concepts unreflectively" and they focus "unthinkingly on the formula needed to solve the problem". Research indicates that when students adopt a deep approach to studying they have a much greater possibility of developing a deep, meaningful understanding of the learning experience (Marton and Saljo (1984) and Trigwell and Prosser (1991)). It is clear that students need to be encouraged to adopt a deep approach to learning before they engage in a learning experience. It seems, however, that the approach students adopt to learning depends on their lecturers' conceptions of teaching (Trigwell, Prosser and Lyons (1997)). It is important for lecturers to reflect on their conceptions of teaching and learning and to appreciate the value of designing learning experiences and assessment tasks which students perceive as encouraging them to adopt a deep approach to learning. Students are unlikely to respond positively to encouragement from their lecturers to adopt a deep approach unless the students perceive that the tasks designed by their lecturers require them to learn in a deep, meaningful way.

Another significant factor which influences the way a student perceives a new learning experience is the student's prior knowledge. Jensen (1995) has explained how research has confirmed that learning is enhanced when new knowledge is related to previously learned material. It is important to activate students' relevant prior knowledge before a new learning experience so that this knowledge is ready to be connected meaningfully to the knowledge from the new learning experience.

Subject readiness packages have been designed by Sleet, Evans, Kalman and Norton (1998) to prepare students for a new learning experience by encouraging them to adopt a deep approach to studying and by activating their relevant prior knowledge. Five key features of these packages are listed below.

- the purpose of each package is clearly explained and, in particular, it is made clear that more meaningful learning results when a learner can relate new learning to previously learned material

- there is a list of the knowledge and skills which students practised in earlier subjects and which also underpin the learning experiences in the new subject

- there is a list of resources (previous lecture notes and laboratory experiments, books and computer software) which students could use to revise these pre-requisite skills and knowledge

- self-assessment questions which test students' understanding of the pre-requisite skills and knowledge are included

- there is a preview of the exciting, new learning experiences in the new subject.

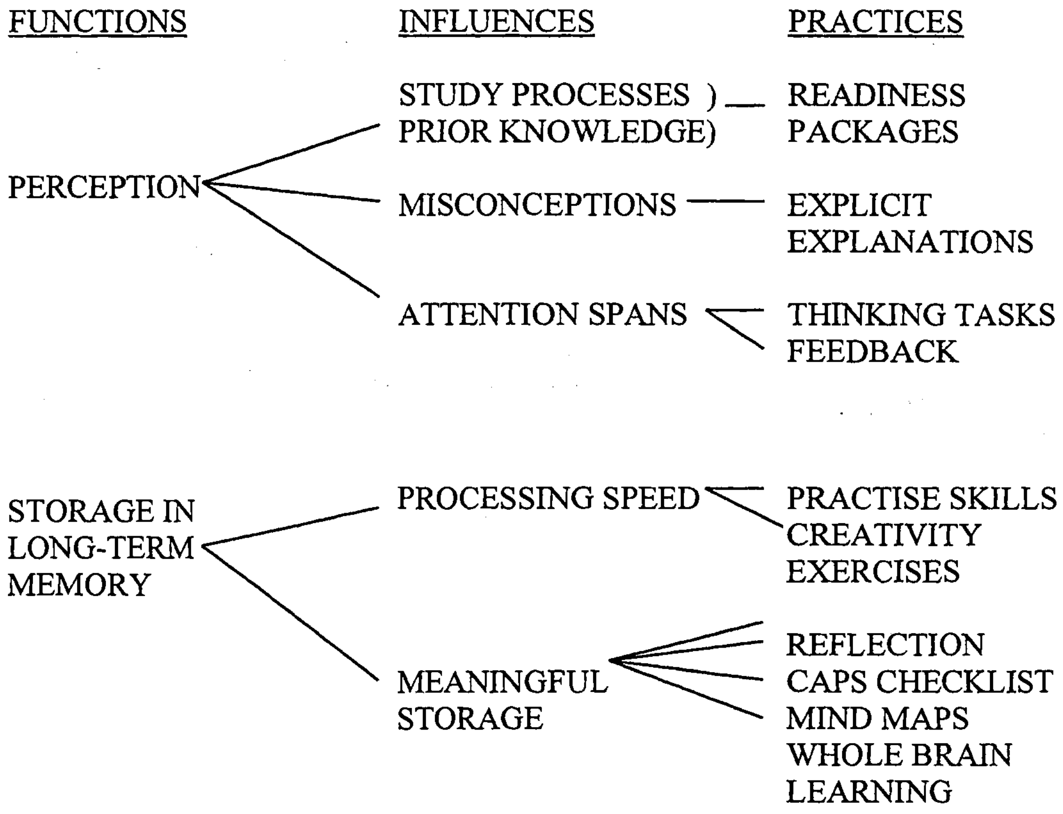



**Figure 2 Relationships between mental functions and teaching and learning practices**

While these packages have yet to be evaluated their development, as explained above, is based on the findings from research. Furthermore, encouraging students to reflect on their prior learning before undertaking the study of a new subject should enhance their understanding of the subject in the same way as pre-laboratory work has been shown by Johnstone *et. al.*(1994) to be effective in enhancing students' understanding of a laboratory experiment.

**Sensing Stage in Perception**

When a student is learning a new topic it is important that the teacher is aware of the misconceptions that research has identified some students develop about the topic. Sleet (1993) in a review of misconceptions pointed out that there is evidence that the language, diagrams or illustrations we use in explaining our conceptions could inadvertently cause the development of misconceptions. For example, Garnett, Garnett and Treagust (1990) have reported that students do develop misconceptions in electrochemistry because they misinterpret language. The statement "salt bridge completes the circuit" used in the description of a galvanic cell was interpreted by some students involved in the study by Garnett et al., to mean that electrons go through the salt bridge. The term STP is interpreted by some students to imply that in thermodynamics the standard state of a chemical depends on temperature. This term is defined by Atkins and Jones (1997, p.155) as "...The expression standard temperature and pressure (STP) means 0°C and 1 atm". On page 197 of the same book, the authors state that the standard state of a reactant or product is the pure form of the chemical at 1 atm pressure. Are these statements on pages 155 and 197 compatible? (Atkins and Jones correctly state that the pressure in their definition of a standard state should be one bar!). I recommend, as I have mentioned previously (Sleet (1993)), to discontinue the use of the term STP.

Sleet (1993) has explained that research by Hill (1988) and others indicate that inaccurate or inappropriate diagrams or illustrations can cause students to develop misconceptions. It is essential that diagrams, illustrations and graphs are annotated to help students interpret them correctly, particularly since these representations often relate to the invisible world of atoms, molecules or ions. Recent studies by Fink, Halligan, Marshall, Frith, Frackowiak and Dolan (1996) using positron emission tomography indicate that in interpreting diagrams or pictures the left hemisphere of the human brain is biased towards processing the local level (the details) and the right hemisphere is biased towards processing at the global level (overall picture). The implication of these findings is that if we want our students to perceive correctly both the overall picture and its details it is important to give the students explicit explanations which assist them to interpret both the local and global aspects of the picture.

If teachers are aware of the misconceptions students can develop then the teachers can be alert to detect during the sensing stage of perception, whether or not any of their students are developing misconceptions. Teachers will be aware of the need to give explicit explanations of their conceptions. It is essential that the development of a misconception is detected as early as possible before the misconception is established in a student's long-term memory. The process called long-term potentiation (LTP) which leads to an increase in the strengths of the synaptic transmissions in the hippocampus in the brain is considered to be the start of the storage of information in long-term memory (Le Doux, 1997). LTP in the hippocampus could be initiated during the sensing stage of perception and eventually the memory of this learning experience could be encoded in the cerebral neocortex which is probably a site of long-term memory. Once a misconception is encoded in the neocortex it is likely to be very difficult for a learner to establish the correct conception strongly enough in long-term memory so that it will be recalled in a variety of contexts while the misconception will always be suppressed. The evidence from neural science about the formation of memories is compatible with the warning made many years ago by Pines and Leith (1981) that it is naïve to think that misconceptions are silly mistakes that can be easily corrected through instruction.

The attention spans of students is another factor which needs to be considered during this sensing stage of perception. How can we engage our students' attention or interest? According to Csikszentmikalyi (1991) if the challenge in learning exceeds the students' skills, anxiety will result and if their skills exceed the challenge, boredom will result. The optimal learning state is when the challenge and skills match. This state is sometimes referred to as the magic learning state (Jensen, 1995). We need to design experiences which challenge our students but at the same time the challenge must not be insurmountable. Students need to feel the satisfaction of solving a difficult task which is important to them. Critical thinking tasks which are novel paper and pencil problems developed by Sleet, Hager, Logan and Hooper (1996) have been found to challenge students. Students generally enjoy attempting these tasks in small groups and evidence has been obtained that students considered the experience of attempting these thinking tasks promoted deep, meaningful learning (Sleet, Logan, Hager and Hooper (1998)).

Another aspect relating to students' attention spans is their ability to concentrate during a lecture. According to Jensen (1995), usually after about 25 minutes in a lecture, adult learners are likely to become inattentive. They need a break for a few minutes before focussing again on the lecture. What kind of activity during this break would be beneficial to the students? My suggestion is to provide an opportunity for the students to test their understanding of the first part of the lecture. It is important to give them immediate feedback about what they have been learning. Jensen (1995) clearly explains that students have a need to know that what they are perceiving is correct. This need for reassurance or feedback is probably related to the fact that the limbic system in our brains, which regulates our emotions, also plays a role in formation of memories. Thompson (1993) states the amygdala which is part of the limbic system, is essential for the initial formation of the memory. Le Doux (1997) considers it has been shown convincingly that the amygdala plays an essential part in modulating the storage and strength of memories. According to Jensen (1995, p.31), "In a learning context, the engagement of emotions at the end of an activity can help the brain to 'know what it knows', to give the needed stamp of approval." The practice of giving students feedback about their learning as soon as possible after each new learning experience can have a significant, positive influence on their learning. It is not surprising that Ramsden (1992, p.99) concluded from studies of students' views about teaching that "Of all the facets of good teaching that are important to them, feedback on assessed work is perhaps the most commonly mentioned."

After the initial experience in learning a new skill or knowledge it is essential that students have opportunities in the future to consolidate that initial learning. Practices which are designed to consolidate that learning by ensuring it is stored effectively in long-term memory, are described in the next section.

**Storage of knowledge in long-term memory (LTM)**

Research indicates that thinking skills will be enhanced if information stored in LTM has the two qualities shown in Figure 2, namely:

- processing speed – that is the information can be recalled and applied quickly (Woods, 1983; McGaw, 1984; Frederiksen, 1984)
- meaningful storage – that is the information is stored as a network of ideas (Kempa and Nicholls, 1983; Hager, Sleet and Kaye, 1994; Buzan and Buzan, 1997).

These two qualities will be considered separately.

**Processing Speed**

Expert problem solvers in chemistry have the ability to process quickly items of chemical information. For example, I am sure experienced chemists on being told the volume of a solution of a pure solute of known concentration can deduce *instantaneously* that they know or can determine the amount in moles of the solute in that volume. The ability to process quickly items of information is an important component of expertise in thinking and problem solving. It is sometimes referred to as automatic processing of information (Frederiksen (1984)). It is a key ability related to the availability of knowledge in LTM and it distinguishes expert problem solvers from novices. Frederiksen (1984) has explained that a great deal of training and practice is likely to be needed to develop the skill of quickly processing bits of information. Hence, in order to develop the skill, students need to be given many opportunities to practise solving simple problems (sub-problems). For example, the sub-problem "Calculate the amount of NaCl in 25.20 mL of 0.100 M NaCl" would afford the opportunity for a student to practise the skill of converting volume and concentration to an amount in moles. Doing sub-problems *only*, however, is not likely to be the most effective way for a learner to develop the skill of quickly processing items of data when the items are embedded in a complex, multi-step problem. For students to solve complex problems they need to develop the ability not only to use or process items of data but also the ability to identify how the data can be processed when no goals are given. For example, it is clearly implicit in the statement of the sub-problem that it is possible to calculate the amount of NaCl from the data given. However, students need to have the skill of recognising that the data in this sub-problem can be used to calculate the amount of NaCl as well as the skill of being able to carry out this process. Creativity exercises developed by Sleet, Shannon and Irvine (1987), are experiences which foster the development of students' abilities to both identify goals and to use or process data to obtain those goals. With a creativity exercise, students are given some information and they are required to deduce or calculate as much chemical information as they can from the given data. The students are encouraged to show all their deductions and calculations, no matter how unimportant they may seem. Creativity exercises have wholly open goals. Examples of creativity exercises are given in Sleet et al. (1987) and Sleet (1991).

**Meaningful Storage**

Figure 2 lists practices which are designed to foster meaningful storage of knowledge in LTM; that is, so that it is stored as a network of ideas. The first practice in the list is the process of reflection. Essentially reflection involves learners making a conscious effort to enrich their understanding of a new topic by asking themselves questions which stimulate them to think about the topic in different ways. My experience indicates that some students need help in identifying what questions they need to consider in order to deepen their understanding. Hence they should be provide with a list of questions they might consider during their reflection. This list is shown in Table 1.

**Table 1. Questions to stimulate reflection**
**(Based on the work of Baird (1986))**

What is the purpose or relevance of this topic?

How does this new topic or knowledge compare with what I already know?

What does the writer or teacher mean here?

Does this information make sense? Do I fully understand this information?
What do I have to remember or understand in order for it to make sense?

What images do I have of this topic or information?
Can I draw pictures to represent my images?

How can I explain what I have learnt on this topic to another student?

I have also devised a checklist called CAPS (see Table 2) which students are required to consider when they review their solutions to the thinking tasks developed by Sleet et al. (1996). The CAPS checklist was designed to stimulate students to check that their solution to a thinking task has employed a suitable range of critical thinking skills. Furthermore, particularly the steps labelled A and S in the checklist (see Table 2) should encourage students to search for connections between their solution and other knowledge stored in their LTMs.

**Table 2. CAPS Checklist**

| | |
|---|---|
| **C** | check that all the **C**alculations, deductions and **C**onclusions are **C**orrect |
| **A** | check that all the **A**ssumptions made in solving the task have been clearly identified and **A**ssessed |
| **P** | check that the answer or answers to the task have a degree of **P**recision consistent with the data or information used |
| **S** | check that the answer or answers to the task make **S**ense. |

Constructing a mind map is another experience which can stimulate students to adopt a deep approach to learning. The process of making a mind map about a topic requires students to identify and clarify concepts related to the topic and to think clearly and deeply about the relationships between these concepts. The technique of mind mapping was developed and is explained in detail by Buzan and Buzan (1997). These authors give detailed advice on how to construct a mind map. For example, they explain why it is important to use images throughout the mind map; why colour is important and why only one key word per line should be used. They also point out that the construction of a mind map "harnesses the full range of cortical skills – word, image, number, logic, rhythm, colour and spatial awareness" (p.84). The importance of responding to or thinking about an experience using all the inherent capabilities of the human brain has also been explained by Atkin (1994) and Jensen (1995). These authors have explained that learning with multiple strategies or multiple modes such as visual, auditory and kinesthetic modes, enhances the quality of learning. Multi-modal or whole brain learning leads to more associations between ideas or information in our brains. Jensen (1995, p.190) asserts that "The greater the number of associations that your brain elicits, the more firmly the information is 'woven in' neurologically". I consider a case can be made, on the basis of the concept of whole brain learning, that the learning of chemistry can be enhanced when students are engaged in games, simulations or role-playing involving chemistry. Lindsay (1997), for example, has described games or role playing as ways of teaching chemical equilibrium and electrolysis. The purpose of the complete set of nine questions listed in Table 1 is to encourage students when they are reflecting about a chemistry concept or topic to think about it in different ways including using words and images; that is to encourage them to engage in whole brain processing. For example, when students are comparing the meaning of the terms 'weak acid' and 'strong acid' they could draw pictures which represent their images of aqueous solutions of weak and strong acids and then explain in words what their pictures mean or represent to them.

De Bono (1990) has developed the concept of six thinking hats to assist people to organise their thinking about an issue so that they will employ one thinking mode at a time instead of trying to do everything at once. He states that "The six hats of different colours represent every basic type of thinking" (De Bono (1996), p.65). I have compared his descriptions of the thinking style associated with each hat and the descriptions given by Herrmann (1990) of the dominant processing styles associated with our cerebral hemispheres. This comparison indicates to me that the thinking styles associated with De Bono's white, black and blue hats are similar to processes in which the left hemisphere is considered to excel whereas the thinking styles associated with De Bono's red, yellow and green hats are similar to processes in which the right hemisphere is considered to excel. The procedure of using six thinking hats as described by De Bono is a thoughtful way to encourage whole brain thinking.

**Conclusion**

The "love of learning" is one of the attributes in the profile of the lifelong learner developed by Candy, Crebert and O'Leary (1994). One of the most important goals in chemical education is to foster in our students a love of learning through a study of chemistry. Ramsden (1992) and Novak (1988) explain that the achievement of this goal depends on students adopting a deep approach to learning. Research indicates that the practices described in this paper should promote deep, meaningful learning and hence the achievement of this outcome should lead to students feeling a sense of enjoyment in learning.

**References**


Atkin, J. (1994) Thinking: critical for learning. In J. Edwards (Ed.), *Thinking: International Interdisciplinary Perspectives.*. Australia: Hawker Brownlow Education

Atkins, P. and Jones, L. (1997) *Chemistry: Molecules, Matter, and Change.* New York: W. H. Freeman

Baird, J. R. (1986) Improved learning through enhanced metacognition: a classroom study. *European Journal of Science Education*, **8** (3): 263-282

Buzan, T. and Buzan, B. (1997) *The Mind Map Book.* London: BBC Books

Candy, P. C., Crebert, G. and O'Leary, J. (1994) *Developing Lifelong Learners through Undergraduate Education.* Commissioned Report No. 28. Canberra. National Board of Employment, Education and Training

Csikszentmikalyi, M. (1991) *Flow: The Psychology of Optimal Experience.* New York: Harper and Row

De Bono, E. (1990) *Six Thinking Hats.* London: Penguin Books

De Bono, E. (1996) *Mind Power.* Australia: Allen and Unwin

Frederiksen, N. (1984) Implications of cognitive theory for instruction in problem-solving. *Review of Educational Research*, **54** (3): 363-407

Fink, G.R., Halligan, P.W., Marshall, J.C., Frith, C.D., Frackowiak, R.S.J. and Dolan, R.J. (1996) Where in the brain does visual attention select the forest and the trees? *Nature*, **282**: 626-628

Garnett, P.J., Garnett, P.J. and Treagust, D.F. (1990) Implications of research on students' understanding of electrochemistry for improving science curricula and classroom practice. *International Journal of Science Education*, **12** (2): 147-156

Hager, P.J., Sleet, R.J. and Kaye, M. (1994) The relation between critical thinking abilities and student study strategies. *Higher Education Research and Development*, **13** (2): 179-188

Herrman, N. (1990) *The Creative Brain.* North Carolina: Brain Books

Hill, D. (1988) Misleading illustrations. *Research in Science Education*, **18**: 290-297

Jensen, E. (1995) *Brain-Based Learning and Teaching.* Del Mar: Turner Point Publishing

Johnstone, A.H., Sleet, R.J. and Vianna, J.F. (1994). An information processing model of learning: its application to an undergraduate laboratory course in chemistry. *Studies in Higher Education*, **19** (1): 77-87

Kempa, R. and Nicholls, C. (1983). Problem-solving ability and cognitive structure: an exploratory investigation. *European Journal of Science Education*, **5**: 171-184

Le Doux, J.E. (1997). Emotion, memory and the brain. *Scientific American*, **7** (1): 68-75

Lindsay, M. (1997). *All work and no play? Alternatives to sedentary chemistry.* Workshop for teachers of senior chemistry. The University of Sydney.

Marton, F. and Saljo, R. (1984). Approaches to learning. In F. Marton, D. Hounsell and N.J. Entwistle (Eds.), *The Experience of Learning: Implications for Teaching and Studying in Higher Education.* Edinburgh: Scottish Academic Press.

McGaw, B. (1984). Acquisition of expertise in problem solving. *Australian Educational Researcher*, **11** (3): 5-26

Novak, J.D. (1988). Learning science and the science of learning. *Studies in Science Education*, **15**: 77-101

Pines, A.L. and Leith, S. (1981). What is concept learning in science? Theory, recent research and some teaching suggestions. *The Australian Science Teachers' Journal*, **27** (3): 15-20

Ramsden, P. (1992). *Learning to Teach in Higher Education.* London: Routledge

Sleet, R.J. (1991). Teaching chemical problem solving. In C. Fogliani (Ed.), *Australian Chemistry Resource Book.* Bathurst: Charles Sturt University-Mitchell

Sleet, R.J. (1993). Attitudes and images in chemistry. In C. Fogliani (Ed.), *Australian Chemistry Resource Book.* Bathurst: Charles Sturt University-Mitchell

Sleet, R.J., Shannon, A.G. and Irvine, B. (1987). A systematic approach to solving closed problems. *International Journal of Mathematical Education in Science and Technology*, **18** (5): 705-715

Sleet, R.J., Hager, P.J., Logan, P.F. and Hooper, M.A. (1996). *Broader Skill Requirements of Science Graduates.* Sydney: University of Technology, Sydney

Sleet, R.J., Evans, L., Kalman, J. and Norton, G. (1998). *Subject Readiness Packages.* Sydney: University of Technology, Sydney

Sleet, R.J., Logan, P.F., Hager, P.J. and Hooper, M.A. (1998). A novel approach to fostering students' critical thinking skills. Submitted for publication.

Thompson, R.F. (1993). *The Brain a Neuroscience Primer.* 2nd edn. New York: W.H. Freeman

Trigwell, K. and Prosser, M. (1991). Relating learning approaches, perceptions of context and learning outcomes. *Higher Education,* **22**: 251-266

Trigwell, K., Prosser, M. and Lyons, F. (1997). *Defining good teaching: relations between teachers' approaches to teaching and student learning.* Paper presented at the 7th Conference of the European Association for Research in Learning and Instruction. Athens

Wood, D.R. (1983). Introducing explicit training in problem solving into our courses. *Higher Education Research and Development,* **2** (1): 79-102

# THE VISCHEM PROJECT: MOLECULAR LEVEL ANIMATIONS IN CHEMISTRY - POTENTIAL AND PITFALLS

**Roy Tasker**

*School of Science, University of Western Sydney Nepean, PO Box 10 KINGSWOOD 2747*

## Abstract

The research literature in chemical education is rich in demonstrations of student misconceptions due to poorly developed mental models of the sub-micro or molecular world. New resources from the VisChem project - Quicktime animations, and Quicktime Virtual Reality (QTVR) objects/panoramas - target many of these misconceptions, and illustrate the link between symbolic notation and molecular structure. However, there is always potential for new misconceptions to be generated, or old ones to be reinforced, from such resources. Some poorly produced animations are now available on CD supplements to chemistry textbooks. The pitfalls in some of these are described.

## Introduction

A rich understanding of chemistry involves being able to link what one *sees* substances doing in the laboratory, to what one *imagines* is happening within these substances at the invisible molecular/ionic level. Only then can these ideas be *communicated* meaningfully using abstract symbolism such as chemical formulas, terminology, and mathematics as shown in Figure 1. Johnstone (1991, 7) refers to the three levels as the *macro*, *sub-micro*, and *symbolic*, and pictures them at the corners of a triangle. Thinking in chemistry is then likened to "moving between a series of points within the triangle, depending on the proportion of the three levels at any one time".

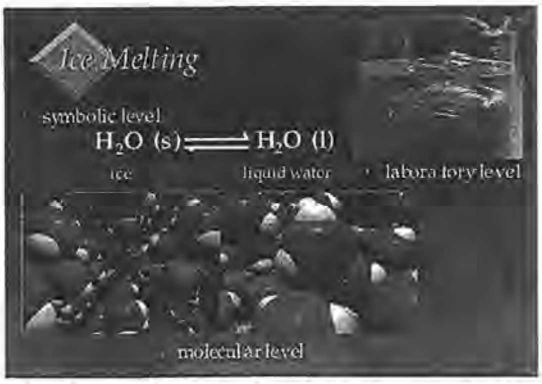



Figure 1 Ice melting at the three 'thinking levels' - the *symbolic* (chemical equation), *laboratory* (ice melting in beaker), and *molecular* (adjacent frames from two VisChem animations – see http://vischem.cadre.com.au)

Due to a shortage of high quality resources that portray the molecular level, most chemistry teaching occurs at the laboratory and symbolic levels, in the hope that mental models of the molecular world will develop naturally. Students are therefore left to develop these models from the static, often oversimplified two-dimensional diagrams in textbooks, or static, often confusing ball and stick models, or from their own imagination. However, there is convincing evidence that many student difficulties and misconceptions in chemistry stem from inadequate or inaccurate molecular models (Lijnse, 1990).

**Computer Animations - The Potential to Portray the Molecular World**

In the VisChem project (http://vischem.cadre.com.au), a team of chemical educators and multimedia developers is producing multimedia resources to explicitly link the molecular, laboratory, and symbolic levels. The most novel resources are a series of computer generated animations which portray substances at the level of molecules, atoms and ions in the solid, liquid, and gaseous states, during phase changes such as melting, and when they react together.

Great care has been taken in the representation of molecular structures and processes since research by Ben-Zvi et al. (1988, 89; 1987, 117) has indicated that misconceptions can be generated easily, and perpetuated, with poorly drawn images.

Visualising the invisible molecular world to generate mental models requires imagination. For example, the speed of atomic and molecular movements, and the uncertain non-Newtonian nature of electrons in atoms, require substantial artistic license to enable the structure and collisions at this level to be represented. For this reason students need to be constantly reminded that these animations are only models of reality.

Animations can show the multiparticle nature of chemical reactions. For example, the laboratory observation of silver crystals growing on the surface of copper metal shown in Figure 2 is hardly consistent with the misleading diagram, often found in textbooks, of one copper atom donating an electron to each of two silver ions. An animation can show reduction of *many* silver ions on the copper surface, with concomitant release of *many* copper(II) ions, in the required two to one ratio shown in Figure 3.

Figure 2

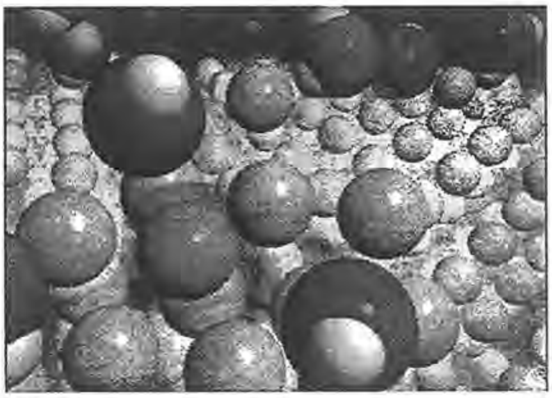


Figure 3

Figure 2. Silver crystals form on the surface of copper metal as the solution gradually becomes blue.

Figure 3. Frame from a VisChem animation showing reduction of silver ions to silver atoms, with the release of copper(II) ions, in a two to one ratio.

In order to imagine what can happen to an ion dissolved in aqueous solution students need a refined model of hydrated ions. The exchange of water molecules around the ions, an introduction to formation of complex ions, the occasional formation of ion pairs, an introduction to precipitation, and the relative migration of hydrated ions in the solution are important images, as represented in Figure 4. A feeling for ion concentration can be gained by imagining the solution when most of the solvent molecules are removed as represented in Figure 5. The separation of ions by an average of three water molecules in a one molar solution conveys a concrete image of an otherwise abstract concentration measurement.

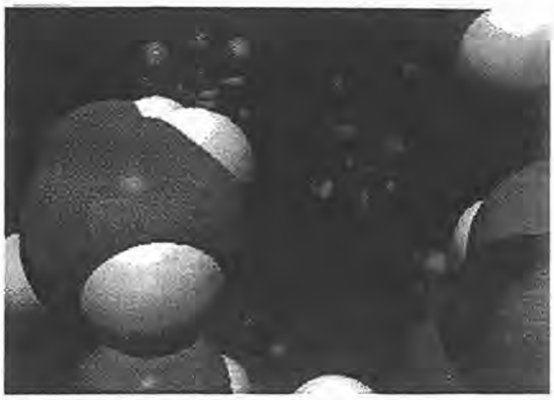


Figure 4 Figure 5

Figure 4. A frame from a VisChem animation portraying a hydrated copper(II) ion about to collide with a hydrated nitrate ion in a 1M copper(II) nitrate solution.

Figure 5. A frame from the same animation with most of the solvent water molecules not shown. Hydrated anions and cations can be seen in the background.

Animations of the molecular world can stimulate the imagination, bringing a new dimension to learning chemistry. What could it be like inside a bubble of boiling water, or at the surface of silver chloride as it precipitates, as depicted in Figures 6 and 7 respectively?

Figure 6 Figure 7

Figure 6. A frame of the VisChem animation which attempts to visualise gaseous water molecules 'pushing back' the walls of a bubble in boiling water.

Figure 7. A frame from another animation which depicts the precipitation of silver chloride after mixing solutions of sodium chloride and silver nitrate.

Analysis of an evaluation pre-test/post-test survey on the VisChem video *The Molecular World of Water: Let's look into it* , involving educators and students at both secondary (14 centres, 450 students) and tertiary (7 centres, 115 students) levels around Australia, was encouraging. The responses from students indicated that after a single viewing of this video they corrected their misconceptions and/or enriched their understanding. For example, 61% of university students demonstrated the misconception that bubbles of boiling water contain air, and this decreased to 25% after viewing the animation described in Figure 6. However, this was only a preliminary study. A longitudinal study to measure long term conceptual changes, and transferability of these images to different substances, is in progress.

Other unpublished work with students in small group interviews has highlighted the potential for new misconceptions to be generated by some students from a VisChem animation. After viewing the animation in Figure 7, two students were curious about the reasons why the water molecules appeared to be carrying the silver chloride ion clusters towards the growing silver chloride crystal. This unintentional impression was communicated by not showing sufficient exchange of hydrating water molecules around the ion as it migrated towards the lattice.

Many molecular processes involve a competition between opposing forces. Examples include the competition for a proton on an iron(III) bound water molecule with a solvent molecule, and between lattice forces and ion-dipole interactions when sodium chloride dissolves in water, as shown in Figures 8 and 9 respectively.

Figure 8

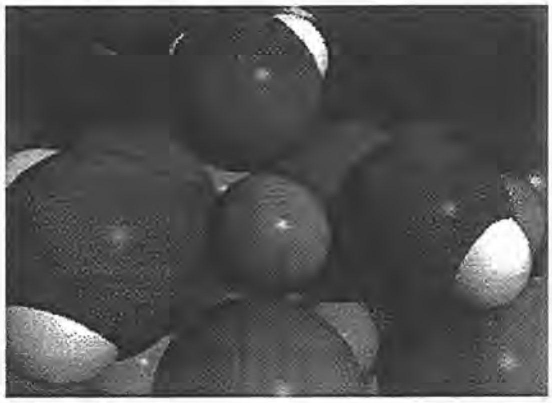


Figure 9

Figure 8 Frame from a VisChem animation showing the 'tug-of-war' for a proton on an iron(III) bound water molecule with a solvent molecule.

Figure 9 Frame from a VisChem animation showing the hydration of a sodium ion on the surface of sodium chloride despite strong attractive forces from the rest of the lattice.

## Misleading Animations

Unfortunately, there is a wide range of quality in molecular animations published internationally on video, CD or over the Net. Compare the frame in Figure 10 below from one animation, with the example in Figure 9. Both animations attempt to portray NaCl dissolving in water. What messages are communicated by these images?

Fig 10 Frame from an animation depicting NaCl dissolving (from *Chemistry: Interactive*, the CD supplement for Ebbing's *General Chemistry*, 5th Ed).

Each animation conveys implicit and explicit information. The animation in Figure 10 suggests that:

- water molecules in the liquid state are widely separated
- solid sodium chloride is composed of ions separated from each other by stick bonds. This image is reinforced by the image of a water molecule passing through the structure (sic!) to hydrate an ion, and by the space left when an ion, with its sticks, is removed from the lattice.

In contrast, the VisChem animation in Figure 9 portrays:

- water molecules in the liquid state as much closer together
- solid sodium chloride as composed of ions, *constantly vibrating*, and closely packed together.

The frames in Figures 11 and 12 are taken from another example of a misleading animation, which is supposed to portray the reaction occurring when aqueous solutions of hydrochloric acid and sodium chloride are mixed. Figure 11 shows distinct HCl molecules in solution shortly before reaction with water molecules! Figure 12 shows NaOH 'molecules' being added in a drop of solution. Animations such as these reinforce the misconception that molecular formulas for strong electrolytes, such as:

$$HCl(aq)$$

and molecular equations such as:

$$HCl \quad + \quad NaOH \dashrightarrow \quad H_2O \quad + \quad NaCl$$

actually describe the species present and processes occurring at the molecular/ionic level. Little wonder students have trouble with understanding electrolytes and concentrations of ions in solution!

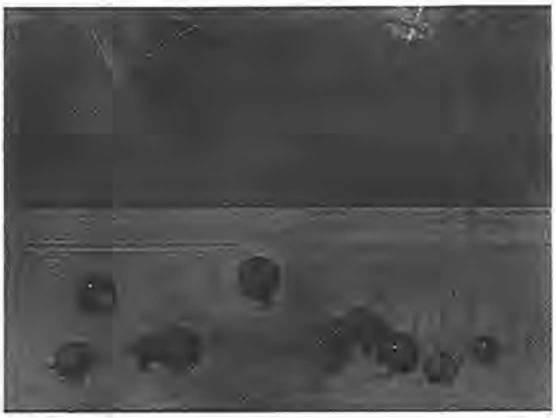


Figure 11

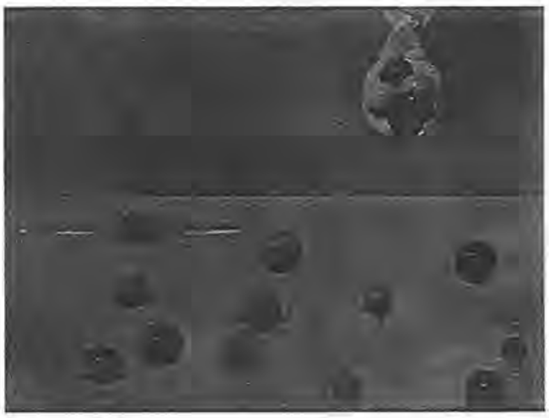


Figure 12

Figure 11 is a frame from an animation depicting hydrochloric acid which shows HCl molecules moving amongst water molecules, shortly before reacting with them!

Figure 12 is a later frame from the same animation, just before a drop of sodium hydroxide solution, containing NaOH ion pairs, is added from a tube above.

(From *Chemistry: Interactive*, the CD supplement for Ebbing's *General Chemistry*, 5th Ed.)

The above animation also illustrates the problem of mixing the laboratory and molecular levels in imagery. Could students develop the idea that a drop of water contains only a few ionic species? Could students develop the image of water composed of water molecules surrounded by some other watery matter indicated by the grey background? Questions such as these are the focus of current action research in the *VisChem* project.

## Multiple Representations of Molecules

One of the most difficult problems for chemistry students is linking two-dimensional formulas to three-dimensional molecular structures. A novel way has been developed to link the symbolic and molecular levels by using the Quicktime Virtual Reality (QTVR) interface. The student clicks and drags the cursor, up or down to move between representations, and left or right to rotate or 'manipulate' the molecule. Frame grabs from two QTVR resources shown in Figures 13 and 14.

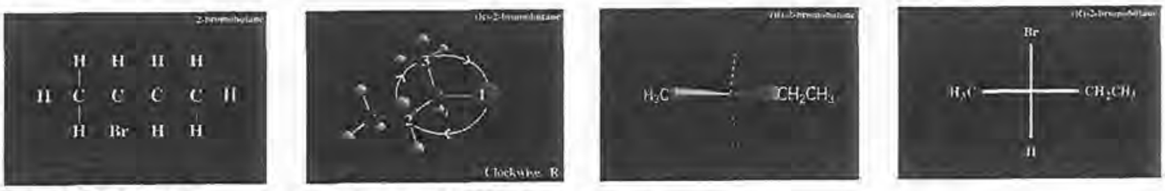


Fig 13 Multiple representations of (2R)- bromobutane

Fig 14 Multiple representations of acetone

In this way students can learn nomenclature rules relating changes in ball and stick models to changes in symbolic representations. They can also see how different representations of molecules can convey different types of information.

## Conclusion

In the new millennium, most information will be communicated using computer-generated multimedia. There is a need to ensure that the same high academic standards that are demanded from text-based information are applied to visual information, which is arguably more effective in conceptual change, for better or worse.

## References

Ben-Zvi, R, Eylon, B and Silberstein, J. (1988). Theories, Principles and Laws. *Education in Chemistry* May, 89-92; Ben-Zvi, R, Eylon, B and Silberstein, J. (1987). Students Visualisation of a Chemical Reaction. *Education in Chemistry* July, 117-120.

Johnstone, AH. (1991). Thinking about Thinking. *International Newsletter on Chemical Education*, 36, 7-11.

Lijnse PL, Licht P, Waarlo AJ and de Vos W (Eds.) (1990) *Relating Macroscopic Phenomena to Microscopic Particles*. Proceedings of Conference at Utrecht Centre for Science and Mathematics Education, University of Utrecht, and references therein.

Tasker RF, Bucat R, Sleet R, and Chia W. (1998) *Research into Practice: Improving Students' Imagery in Chemistry* Manuscript in preparation.