Guide for contributors to the Australian Journal of Education in Chemistry

Introduction

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

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

Articles

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

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

Reference Styles

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

Copyright

Your manuscript should not have been published already nor should it have been submitted for publication elsewhere. If AusJEC publishes your manuscript then it will become the copyright of the Royal Australian Chemical Institute. The RACI will, however, allow you to use the contents of your paper for most reasonable non-commercial purposes.

In this issue ……….

From the Australian Physical Chemistry Enhanced Learning in Laboratories (APCELL) program, the paper by **Barnett** describes how students can construct their own simple sucrosemeter using a He-Ne laser and a hollow equilateral prism. Diffraction of the laser beam by sugar solutions placed in the prism can be calibrated to measure sucrose concentration. Apart from providing an experience of instrumentation even at the first-year level, it is claimed that this transparent apparatus can enable students to recognise the function of each component - unlike most of today's 'black-boxes'. Furthermore, it provides opportunities for critical evaluation of the strengths and limitations of the instrument and its design, and to distinguish the limitations from human sources of error. In fact, this critical evaluation of the simple instrument - usually not possible in more sophisticated instruments - is claimed to be one of the most significant advantages of the sucrosemeter.

Lim discusses another experiment which is an outcome of the APCELL range. This experiment investigates, spectrophotometrically, the kinetics of oxidation catalysed by the enzyme *o*-diphenol oxidase, as well as the kinetics when there is a competing reaction due to the presence of an inhibitor such as *p*-nitrophenol or cyanide. This can serve two functions: to relate physical chemistry to a biological 'real world' situation, as well as to provide a more complex system than traditional kinetics experiments, with many levels of challenge for students.

Confusion over conception of the mole as a number or as a means of comparing one chemical amount with another is addressed by **Morikawa and Newbold**. In this rather analytical paper, they develop the concept of one-to-one correspondence between elementary entities. They claim that this can clarify the meaning of the dimension 'amount of substance', and suggest a modification of the IUPAC definition.

Beasley and Ocampo present an important paper in these times of pressure to improve teaching at the tertiary level. The paper reports on the challenges faced by a group of professors of chemistry and chemical engineering in Argentina who undertook a professional development course based on analysis of their own teaching practices. The action learning model of the course used a cycle involving reflection upon four influences: public knowledge, professional practice, worldview and praxis. The course seems to have been successful in raising self-awareness of changes that the participants might adopt. However, investigation two years on showed that the intended courses of action had not been 'institutionalised', largely because of perceptions of external constraints.

In a chemistry education research paper, **Head and Bucat** report on an investigation of the three-dimensional visualisation abilities of tertiary chemistry students and staff. Participants were given tasks involving mental manipulation of molecular structures, such as recognising enantiomeric relationships between drawings of molecules. Student abilities vary widely. More interestingly, and perhaps more significantly, it was shown that a wide range of approaches to the tasks were used, and each person consistently employs an idiosyncratic approach. They point to the potential problem that an explanation used by a lecturer is necessarily at odds with the approach of at least some students.

Duggan reviews the book *Carbohydrates: The Sweet Molecules of Life*, authored by R. V. Stick (Academic Press, 2001) and **Mitchell** presents another interesting discussion in his column *The Word on Chemistry.*

RACI Chemical Education Division Standing Committee - Contact Details.

Editorial

As this volume goes to press, the early bird registration deadline for the National Conference of the Chemical Education Division of the Royal Australian Chemical Institute is here. The conference is at the University of Melbourne from 30 November till 4 December, and information can be obtained at http://www.deakin.edu.au/fac_st/bcs/RACI_ChemEd/Chem_Ed_Nat_Con_2002.html. Let's hope that we will see lots of people there who do not necessarily identify themselves primarily with the 'chemical education community'.

Those involved in chemical education – indeed those involved in chemistry in any way – ought to know that the International Union of Pure and Applied Chemistry has in recent times focussed its activities less through committee work and more through projects with defined objectives. Applications for project funding are open to anybody – not just IUPAC members.

It is perhaps worth listing the general criteria:

IUPAC projects should address one of the goals listed in the IUPAC Strategic Plan and satisfy at least one of the following key criteria:

- They should be related to the needs of the chemists in the world, not just in a country or a region.
- They should be related to the role of chemistry for the needs of mankind.
- They should best be approached by an international team such as IUPAC can assemble.

And, by way of further definition of what constitutes appropriate projects, IUPAC have published a list of examples:

- Studies of problems of international nomenclature, symbols, terminology and conventions, as the need develops.
- Large future-oriented projects important for the position of chemistry in the world or for the needs of mankind (CHEMRAWN, teaching of chemistry, problems of publications or of computers, mission-oriented programmes, etc.).
- Compilations with critical evaluation of data best undertaken by an international team, especially compilations of interest to the broader international chemical community (e.g., solubility data, electrode potentials). Data compiled from literature without critical evaluation or obtained experimentally in a single laboratory are less appropriate.
- Unification of "approved" experimental methods (in particular those related to analytical problems, characterization of materials, etc.), establishment of standards and reference materials, recommendations on procedures of interest in many laboratories, in domains where specialized organizations (ISO, EU, NIST) are not active, or in close cooperation with them.

And further advice:

- IUPAC Divisions and Standing Committees should prioritize their activities to stress those of the greatest importance with the greatest impact and interest to the international chemical community.
- Projects which are inappropriate for IUPAC include review articles, especially those by a single author that might ordinarily be published in the existing review literature (*Chem. Rev., Angew. Chem*., etc.), purely informational projects (e.g., surveys of methods or materials without critical evaluation), original research studies, experimental studies and recommendations from a single laboratory.

These projects offer a golden opportunity to make a worthwhile contribution involving international collaboration. There have been a number of chemical education-based projects which have come to fruition, and it seems that this field is well suited to participate in this program. A list of current project in all areas of chemistry, with links to descriptions and rationales, is available at http://www.iupac.org/projects/current_projects.html

More details and application procedures can be found at the IUPAC website

http://www.iupac.org/projects/index.html#info

RBB

An invitation

The editors invite readers to make contributions to this Journal.

As well as papers submitted for peer review, we welcome any of the following:

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

Laser-based liquid prism sucrosemeter: An APCELL experiment.*

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The majority of disciplines in science involve instrumentation to provide meaningful data for a wide range of applications. The automation of many modern instruments means the user can often obtain reliable data easily without requiring an in-depth understanding of the underlying science. Such automation (including computer-interfaced data acquisition) is extremely beneficial to the scientist and researcher, but can actually detract from student learning in a practical sense as it compels the student to rely solely on theoretical knowledge to understand potential limitations and overall reliability of acquired data. Students often have difficulty in achieving this, particularly when core components of an instrument cannot be clearly observed.

While the chemistry involved in this experiment is not challenging (refraction of light as a consequence of refractive index), its main benefit is that it reinforces the importance of critically assessing instrumentation and experimental design when considering data reliability (as opposed to attributing all error to 'experimental error').

The experiment focuses on instrumentation that is entirely transparent and easily controlled by the student. They construct their own analytical instrument that has an observable response signal (visible laser beam diffraction), enabling students to directly recognise the function of each core component. Using their instrument to perform analysis of real samples reveals not only the success of the instrument but also limitations in its applicability. For successful analyses, students consider accuracy and precision of their instrument. This is aided via a comparison of their experimentally obtained data with data obtained from a commercial instrument as well as literature values. For analyses that were not successful, students further explore experimental design by considering modifications to their set-up that could overcome its current limitations.

Educational Template

Section 1 - Summary of the Experiment

1.1 Experiment Title

Laser-Based Liquid Prism Sucrosemeter.

1.2 Description of the Experiment

In this experiment students construct their own sucrosemeter using a He-Ne laser and hollow equilateral prism. Sugar solutions are placed in the prism and the diffraction of a laser beam through these solutions can be monitored as a function of concentration, enabling determination of 'real' unknown solutions (cordial, soft drinks etc.). If available, a commercial refractometer is an ideal addition to the experiment as students can compare the results of their constructed sucrosemeter to the commercial one.

The benefits to student learning in this experiment are more of a general nature than specific to concepts presented by lectures. The fact that real samples are analysed is always a plus to student learning. Technical skills in making standard solutions and drawing results from calibration curves expose the student to core analytical skills.

Constructing their own apparatus which is simple yet yields accurate results reinforces in students that instrumentation and design do not always need to be complicated or expensive. With continued advances in the technology of instrumentation as well as interfaced data acquisition software, it is easy for students to simply 'press a button' to obtain results without considering the chemistry that occurs within a fully enclosed instrument. The simplicity of the experimental set-up as well as the transparency of the response signal (visible laser beam diffraction) in this experiment encourages students to consider 'cause and effect' components of instrumentation. Students critically analyse experimental design by probing both strengths (reliable determination of refractive indices and sucrose concentrations) and limitations of their experimental set-up (analysis of dilute samples and samples of complementary colour to the laser beam cannot be reliably made without modifications to the design and/or sampling). Comparison of direct readings of diffraction angles to calculated angles also encourages students to assess accuracy over simplicity when considering data collection methods (for this experiment, direct readings of deflection angles gives poor accuracy, whereas calculated angles yield great accuracy due to relatively small error propagation).

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

1.3 Course Context and Students' Required Knowledge and Skills

This experiment has little direct linkage to general course material in Physical Chemistry, unless a component regarding refraction of light through prisms / solutions, Snell's Law, simple laser chemistry etc. is incorporated. Indirectly, this experiment can enhance a student's confidence in his/her own ability to simplify and comprehend new concepts taught in Physical Chemistry. (New concepts in Physical Chemistry can be difficult for students to grasp if the language and mathematical relationships overwhelm them - this experiment is easily understood, and the associated mathematics is easily applied.)

Minimal prior knowledge is required by students to successfully conclude this experiment. Advantageous skills to have are competency in using volumetric techniques / glassware, basic knowledge of light refraction trends and adeptness in constructing and applying calibration curves.

The experiment as presented here is undertaken by our second year students, however I feel that it is simple enough to be adapted as a first year practical.

1.4 Time Required to Complete

Prior to Lab	30 min - 1 hr (reading)
In Laboratory	2 – 3 hrs
After Laboratory	2 – 3 hrs (plotting data, analysing results, calculations, report writing)

1.5 Acknowledgments

This experiment was adapted from "Narayanan, V.A. & Narayanan, R. *Laser-based Liquid Prism Sucrosemeter – A Precision Optical Method to Find Sugar Concentration*. J. Chem. Ed., 74 (2), 1997".

1.6 Other Comments

In my opinion this experiment is not very challenging when compared to other experiments offered by us at second year level. Despite this, I find it works very well in the laboratory as it incorporates several analytical methodologies common to many experiments. When the students are exposed to the second year laboratories (esp. physical chemistry) for the first time, they are often overwhelmed by the instrumentation, equations involved in analyses and graphing techniques that they have had little prior experience in. This experiment enables students to "re-focus" on many common features of experiments (calculations, using equations, linearity relationships and subsequent calibration curves, error analysis) in a straightforward easy to follow way. I have found that students sometimes gain a better perspective on the subject area as a whole when they are able to "practice" common features (such as graphical analyses) using a protocol that is easy to follow and understand, and has very little prospect of failing to yield reliable results.

As a learning tool this experiment is most effective if it is extended to incorporate scenarios where the design yields accurate and reliable data as well as scenarios where accuracy is not possible without modifying the design and/ or approach. In general, students often attempt to designate poor results to 'experimental error' (error in pipetting, human error in weighing etc.). In many cases such sources of error cannot significantly account for deviations in response signals (for example if the concentration range is beyond an instruments detection limits, or if specified conditions for optimal output are not maintained). It is therefore imperative that students develop the ability to critically assess experimental limitations and distinguish these from sources of error. Addressing limitations in their experimental design and exploring ways to overcome these can precipitate such critical assessment in students.

It is intended to incorporate comparison of student's results to results they obtain when using a commercial refractometer. The attached experimental write-up has not been modified to incorporate this as we are yet to trial the refractometer we have available to us.

On a further note, it is a reliable simple analytical experiment that can be very cheap to set-up and maintain. Commercial sugar and cordials are the only consumable expenses; the He-Ne laser could be replaced with a commercial laser pointer; the hollow prism could be constructed using microscope slides.

Section 2 – Educational Analysis

Learning Outcomes *What will students learn?*	**Process** *How will students learn it?*	**Assessment** *How will staff know students have learnt it?* *How will students know they have learnt it?*

Theoretical and Conceptual Knowledge

The importance of critical appraisal of theories and conceptual applicability.	By observing a) successful outcomes of their experimentation as well as b) limitations in the applicability of their set-up: a) Students use theoretical relationships to calculate refractive index values of samples from experimental measurements. By comparing their results to literature values (and/or measurements from a commercial refractometer), students can see the accuracy of their experimental design. b) By considering and observing scenarios where the experimental design would not be applicable in the current set-up (dilute solutions and complementary coloured solutions to laser beam) encourages students to critically address concepts rather than to simply accept them.	Accuracy of experimentally determined values as compared to theoretically obtained values. Explanations of reasons for observed limitations of the experiment. Discussions of further potential applications of the experimental design (instigated by questions posed in the manual), emphasising consequential limitations and ways to overcome these. These points are assessable via the submission of a written report, as well as oral communication with the demonstrator at the conclusion of the experiment.

Scientific and Practical Skills

Ability to collate, correlate, display, analyse and report observations.	By recording experimentally obtained data and then using this data to determine standard properties of their samples (refractive index, concentration): Students clearly see the response signal they measure (laser beam deflection). They recognise trends in this response signal to sugar concentration (a linear relationship) and can hence use their results to determine sugar concentrations of real samples. By applying experimental data to theoretical relationships (from the measured response signals, deviation angles are calculated which are then used to calculate refractive index values) and comparing values to literature values, students can see further applicability to their experiment design than simple concentration analysis.	Students must collate a written report on their experiment, which is based on a standard format which is clearly outlined in their manual. This is a weekly requirement in our laboratories, so students become aware that they are effectively mastering this requirement as it becomes quicker and easier for them to collate their reports as their experience grows. Assessment is largely biased towards the student's ability to describe the relevance / theory of the experimentation, as well as their ability to discuss the significance of their results. Each practical report is marked by one demonstrator only, so the demonstrator can obtain a general idea of the experiment's success (in lieu of student comprehension as well as accuracy in experimental output) due to repetitive assessment over the course of one semester.

Ability to consider limitations as well as successful applications of experimentation.	As well as any sample a student may choose, they also analyse provided samples that can be reliably analysed using their experimental design (most cordials, soft drinks, etc.). Other samples are also analysed that cannot yield reliable results without modifying their experimental design (e.g. cordial of complementary colour to the laser beam, and solutions that fall outside of the calibration range that can be accommodated by the design). Students therefore directly observe strengths as well as limitations of their experimental design.	By explaining why one sample was unable to be analysed whereas all other samples were successfully analysed. Questions posed in the manual guide students to explain reasons for the experimental limitation they observed (as well as others) and assist students to consider modifications of the experimentation that could overcome limitations. This is assessed via verbal communication as well as discussions presented in the student's written report.
Understanding the operation of instrumentation.	The transparency of the cause and effect response (visible laser beam refraction) being measured as a function of concentration enables the student to see clearly the operation of the instrumentation. Comparing their experimental results to results obtained using a non-transparent commercially obtained refractometer encourages students to translate their direct observations to other instrumentation, realising that the majority contain core components that induce a detectable affect on a sample which can be converted to meaningful data.	As above, orally and via written reports.
Ability to present reports in appropriate formats.	By constructing a written report on conclusion of their experiment, following (if desired) clear guidelines presented in their manual.	Assessment of their written report is based not only on content, but also on appropriate presentation adhering to standard form (e.g. abstract, aim, introduction, experimental, results, discussion, conclusion, references).

Generic Skills

Problem solving: ability to apply problem solving in familiar and unfamiliar situations, and to display the capability of rigorous and independent thinking.	After observing predictable and reliable trends in the response signal to various standard solutions (variation of response is proportional to sugar concentration), students are given an unknown solution to measure in which the response signal cannot be observed. Students are not forewarned of this, and therefore undergo a more complete 'trouble-shooting' process. For some students, this is a quick process as they realise that the conjugate coloured solution absorbs the laser beam. Other students repeat their sampling and measurements of the 'wayward' unknown, double checking procedures used by their partners. After observing a failure to obtain a result after such repetition, students must then critically appraise their experimentation to determine why the initial successful application of their experiment has failed. Most students realise (sooner or later) what is happening with little or no prompting from the demonstrator.	By addressing questions posed in the manual as well as explaining experimental limitations, students will have successfully extended themselves regarding problem identification and solving. Demonstrators will be able to assess this process by observing the student's approach to identifying experimental limitations and ways in which to overcome them (as well as explanations to questions posed in oral communication and the written report).

Working with others: one-to-one and in teams, understanding and responding to the demands of the task and working effectively to achieve a shared goal, coping with set backs.	The experiment is typically undertaken in pairs, with sharing and / or division of tasks being established by the students themselves. When limitations of the experimental design (after obvious success) are encountered, the students work together to discover why, with resolution often being achieved prior to consulting the demonstrator. On occasion, students will question each other's technique before questioning the experimental design or a demonstrator. Teamwork can be enhanced when the students determine that neither they nor their partner have erred.	Teamwork is noticed as being effective during the course of the experiment, by observing the students setting up the equipment, as well as running the experiment and analysing and interpreting data, as well as addressing questions posed in the manual. Poor teamwork can sometimes be noticed if a student does not have all relevant measurements in their written report after the laboratory session (e.g. accurate masses of sugar weighed for preparation of standard solutions). Oral assessment at the conclusion of the experiment is usually performed by the demonstrator on each group rather than individual students. During this time, the demonstrator discusses points of the experiment with each student in the group.
Critical analysis: evaluating relevance and relating knowledge to the real world.	Students critically analyse their experimental set-up by comparing calculated values to theoretical values (and commercial instrumentation if available). They consider the accuracy of their method, and address limitations (both experimentally determined as well as hypothetical situations directly relevant to realistic scenarios). The students measure concentrations of sugar in real 'everyday' samples.	Assessed as per methods already discussed.
Life-Long Learning: the capacity for and commitment to life-long learning.	Students learn this skill as they are directly in control of the entire experimentation themselves (from setting it up to concluding reliable information). They set up their own apparatus and question its application in contexts where success is evident as well as in situations where success requires further modifications.	This is normally evident in the students written report (usually written during the week following the experiment). A student who has mastered this particular skill will normally present a report on successful experimentation, with suggested modifications that would extend its applicability. Students who require further experience in attaining this skill will often report limitations to the experimental design rather than extended modifications to the instrumentation.

Section 3 - Student Learning Experience

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

Yes, fairly simple concept. The intro & theory section said everything involved.

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

It's another good (& simple) example of analytical chemistry. Lasers are always fun.

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

Yes. I think analysing unknowns was interesting.

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

Yes & yes.

3.5 Does this experiment require teamwork and if so, in what way? Was this aspect of the experiment beneficial?
When taking the angle measurements.

3.6 Did you have the opportunity to take responsibility for your own learning, and to be active as learners?
I guess so, if you mean learning from the intro & theory. Graphing and interpreting is always a satisfying end to an experiment.

3.7 Does this experiment provide for the possibility of a range of student abilities and interests? If so, how?
It's not too challenging (reminiscent of high school physics) – which is nice once in a while.

3.8 Did the laboratory notes, demonstrators' guidance and any other resources help you in learning from this experiment? If so, how?
Lab notes for theory, demonstrator for set up of equipment.

3.9 Are there any other features of this experiment that made it a particularly good or bad learning experience for you?
Good – comparison of measured and calculated values.

3.10 What improvements could be made to this experiment?
None really – maybe just get students to test more unknowns.

3.11 Other Comments
[no responses]

What's in a formula? - Pedagogical content knowledge

Formulas of elements and compounds provide information about the substances that they represent. For example, He refers to a substance that consists of monoatomic molecules, N_2 represents another that consists of diatomic molecules and P_4 is the formula of another that has four atoms in each of its molecules. Why then don't we use S_8 to represent solid sulfur? After all, we use C_6H_6 for benzene, and not CH. But C_∞ for diamond? Maybe the answer lies in balancing complexity and the amount of information provided by the formula.

Sometimes the information in a formula is hidden unless we have an understanding of the nature of the substance. For example, chemists 'know' that He, Na and Si do not all refer to substances that exist as monoatomic molecules. And the formulas SiO_2 and CO_2 may look similar, but they mean vastly different things to the person with a knowledge of structures. To be specific, the formula, SiO_2 for silicon dioxide - a covalent network substance - is taken to mean that in silicon dioxide there are twice as many oxygen atoms in the network as there are silicon atoms. In a sample of carbon dioxide there are twice as many oxygen atoms as carbon atoms, but the formula CO_2 provides the additional information - if you understand carbon dioxide to be a molecular substance - that each molecule of carbon dioxide has one carbon atom and two oxygen atoms. In summary, SiO_2 tells us about relative numbers, but CO_2 tells us about absolute numbers.

Sometimes we use formulas to indicate structural information. For many compounds, there may be various acceptable formulas, each providing a different amount of information. For example, benzaldehyde may be represented by either C_7H_6O or C_6H_5CHO. The first tells us only the composition, while the second provides information about the structure of the molecules.

But then the formula of sulfuric acid is almost always written as H_2SO_4. This formula represents the composition of the molecules accurately, but does it suggest to the novice that the hydrogen atoms are joined to the sulfur atom? Given that each hydrogen atom is bound to an oxygen atom, is $SO_2(OH)_2$ a preferable formula?

An interesting question is how to represent the formula of ammonium iron(II) sulfate-6-water (ferrous ammonium sulfate hexahydrate). The formula most commonly found on the labels of bottles is $FeSO_4.(NH_4)_2SO_4.6H_2O$) - a typical formula for the 'double salts'. However, this formula almost implies that there are two compounds present: iron sulfate and ammonium sulfate. It suggests that half of the sulfate ions are associated with the iron(II) ions and the other half with the ammonium ions.

A more acceptable view of the structure of this compound is of a lattice containing sulfate anions, and both iron(II) cations and ammonium cations - as though half of the Fe^{2+} ions in an iron(II) sulfate sample have been replaced by twice as many NH_4^+ ions. So a preferred formula might be $Fe(NH_4)_2(SO_4)_2.6H_2O$.

Then again, X-ray diffraction studies on crystals of ammonium iron(II) sulfate indicate that the waters of crystallisation are all bound to the iron(II) ions. So perhaps we should show this in the formula by representation of the hexaquairon(II) complex ion in the

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Inhibition of the reaction kinetics of the enzyme o-diphenol oxidase: An APCELL experiment.*

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Introduction

Chemical kinetics is a fundamental component of chemistry. Traditional chemistry-laboratory exercises have concentrated on the study of non-biological organic or inorganic reaction kinetics. Historically, these experiments are chosen for their perceived didactic value — they usually exhibit simple kinetics, without complicating factors — rather than for any "relevance" to the world outside the chemistry laboratory. The same lack-of-relevance is applicable to many "traditional" experiments in other areas of chemistry. Therefore, the fact that students are avoiding the study of chemistry (*1*), should not be surprising.

The aim of this experiment is to investigate the kinetics of an enzyme-catalysed reaction, and the kinetics in the presence of an inhibitor (*2-15*). This relates physical chemistry to a "real world" application — the action of a biological catalyst, o-diphenol oxidase (oDPO). Better students need to be challenged (*16*) by extentions to the experiment, which is easily achieved since the complexity of biological systems offers many avenues for exploration.

Enzyme kinetics is usually described by the Michaelis-Menten model, which can be used to illustrate several concepts in the curriculum. The behaviour of enzyme-catalysed reactions is **not simply** proportional to the power of the reactant (substrate) concentration [S]. The kinetics changes from being first-order with respect to [S] at low [S], to being zeroth-order at high [S], with non-integer order at intermediate [S] (*3-10*). The derivation of the Michaelis-Menten kinetic equations involves use of the quasi-steady-state approximation (*3-6*). Furthermore, the laboratory is an opportunity to learn how to handle photo-sensitive reagents.

The original version of this laboratory exercise used *p*-nitrophenol and cyanide anion inhibitors. Other inhibitors (*15*), with smaller health and safety risks, can be used: eg NaCl (10 mM stock) under the conditions described in the notes, has been successfully used at Deakin University.

This exercise has the potential to be further developed as an affordable high-school experiment using the browning of mashed raw fruit or potatoes as the enzyme-catalysed reaction and a home-made colorimeter for under $15 (*17*). In this configuration, the most expensive items of equipment or reagents would be a sturdy kitchen knife and food processor!

Acknowledgements

The author wishes to thank: Ms Jeanne Lee(李静宁) for introducing him to an earlier version of this experiment and for encouraging and helpful discussions; Dr Robert Learmouth (University of Southern Queensland) for giving permission for his version of the experiment to be adapted and developed at Deakin University; Dr J.R.L. Walker (retired, University of Canterbury) for documentation on experiments using oDPO extracted from mushrooms and bananas, and for a reprint of reference (*14*); members of the APCELL team and undergraduate students at Deakin University for useful feedback and suggestions.

Educational Template

Section 1 - Summary of the Experiment

1.1 Experiment Title

Reaction Kinetics. Inhibition of the Enzyme *o*-Diphenol Oxidase

1.2 Description of the Experiment

Chemical kinetics is a fundamental component of physical chemistry. The aim of this experiment is to investigate the kinetics of an enzyme-catalysed reaction, and the kinetics when there is a competing reaction due to the presence of an inhibitor (*2-15*). This relates physical chemistry to a "real world" application — the oxidation of an organic compound through the action of a biological catalyst.

1.3 Course Context and Students' Required Knowledge and Skills

The School of Biological and Chemical Sciences at Deakin University has students enrolled in the biology, biotechnology, forensic and wine science streams as well as the chemistry stream: the physical chemistry unit has to cater for a wide range of student interests and mathematical skills.

One of the foci of the School is the promotion of the

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

interdisciplinary nature of modern chemistry (via "biologically relevant" chemistry) and of modern biology (via molecular biology). Instead of doing a "traditional" kinetics experiment, an enzyme kinetics reaction is studied, also with inhibition via a competing equilibrium (here "competing equilibrium" is used in the usual chemical sense, meaning alternative pathway).

This kinetics experiment is the third experimental exercise (total of five such experimental exercises) done during the semester-long 2nd year physical chemistry laboratory.

- Students are expected to have knowledge of 1st year kinetics and 1st year equilibrium topics.
- Prior to the start of this laboratory exercise, students have been introduced to the use of a spreadsheet package. Nevertheless, students are told that use of a spreadsheet is part of the computer laboratory component of the exercise and should consult their demonstrator if they encounter difficulties.
- Students are not expected to have knowledge of kinetics or equilibrium topics at 2nd year level. An appendix introducing enzyme kinetics is included in the student notes for those students who are unfamiliar with the topic.

Some students may have encountered enzyme kinetics in Biochemistry during the first semester of second year. Those students would have done a biochemistry laboratory exercise on enzyme kinetics (Michaelis-Menten kinetics), but not an exercise on *inhibited* enzyme kinetics. Over half the students attempting *this* laboratory exercise would *not* have attempted the biochemistry laboratory exercise.

1.4 Time Required to Complete

Prior to Lab	1 hour reading
In Laboratory	2 hours "wet" laboratory and 2 hours "dry" laboratory for analysis of results
After Laboratory	2-3 hours report writing

1.5 Providence

The original source of this experiment is unknown.

Kieran Fergus Lim (Deakin University) and Robert Learmouth (University of Southern Queensland) both have versions of this experiment derived from an experiment run by Robert Learmouth when he was at University of New England (*c*. 1990). Robert Learmouth has given permission for the experiment to be adapted and used.

Verbal tradition at University of New England suggests that the experiment came from the University of Sydney (*c*. 1960s? 1970s?), but current Sydney staff (*c*. 2000) have no knowledge of the experimental exercise.

Many similar experiments (mostly on ***un***-inhibited Michaelis-Menten kinetics) have been published in the literature: for example, (*14,15,18-23*).

1.6 Other Comments

J.R.L. Walker (retired, University of Canterbury, New Zealand) has run a similar experiment using the same enzyme extracted from mushrooms and bananas. Extraction from other fruit is also possible. The University of Canterbury experiment usually used the kinetics to determine comparative concentrations of *o*-diphenol oxidase enzyme (oDPO or tyrosinase) in different parts of the mushroom, and hence was not a kinetics experiment as such. Walker has published a paper on the inhibition of o-diphenol oxidase by phenolic acids (*14*) and gives a list of inhibitors of o-diphenol oxidase activity in (*15*).

In the student notes, *p*-nitrophenol and cyanide anion inhibitors were described for historical reasons. One of the referees has pointed out that use of these inhibitors poses health and safety risks: we have since used NaCl (10mM stock) as an inhibitor: other inhibitors of o-diphenol oxidase activity (*15*) are also possible.

ionic lattice, and use the formula $[Fe(H_2O)_6](NH_4)_2(SO_4)_2$.

But we have to be careful. How should we represent the formula of nickel chloride-6-water whose composition is represented by $NiCl_2.6H_2O$? In view of what has been said above, we might think that the formula $[Ni(H_2O)_6]Cl_2$ provides structural information. Well it would - but incorrect information! Crystallographers tell us that each nickel ion forms a complex with four water molecules and two chloride ions. The other two water molecules in the lattice are not directly bound to the nickel ions. So perhaps $[Ni(H_2O)_4Cl_2].2H_2O$ is the most appropriate structural formula.

Where do we stop? Presumably our best guide is provided by the purpose for which a formula is being used.

The really important message in this discussion is that how we interpret the formula of a substance usually depends on prior knowledge about the substance. And it is often the case that students don't have the knowledge that allows them to interpret formulas in the same way that experts do. And perhaps it's not surprising that sometimes they are confused!

RBB

Section 2 - Educational Analysis

Learning Outcomes *What will students learn?*	**Process** *How will students learn it?*	**Assessment** *How will staff know students have learnt it?* *How will students know they have learnt it?*

Theoretical and Conceptual Knowledge

Students must understand and use the relationship between the transmitted light intensity of a 'blank' and the transmitted light intensity of the sample, in order to determine the absorbance of the sample using a single-beam spectrophotometer.	These three fundamental concepts underpin the entire exercise	Students are able to convert their light intensity (transmittance or "absorbance") measurements into reaction rates
Students must understand and apply the Beer-Lambert Law in order to use absorbance to measure concentration (or at least concentration in arbitrary units).		
Students must understand the definition of reaction rate in order to measure rate (in arbitrary units) by the change in concentration (in arbitrary units) over time.		
Students should appreciate that reaction kinetics is applicable to real-life systems, not just systems involving methyl isocynide and other "textbook" systems.	Students will measure kinetics associated with a food stuff	
Students should appreciate that complicated reaction mechanisms (like the Michaelis-Menten mechanism) will give rise to non-integer reaction orders.	Use of the Michaelis-Menten reaction kinetics.	Students are able to see to see that a rate versus reactant (substrate) concentration curves from linear proportionality (first order) to being constant (zero order) at high reactant concentration. Staff will know from the students' discussion of the Michaelis-Menten reaction kinetics.
Students should be able to exercise judgement about what is (or is ***not***) relevant in the context of the exercise, judgement about what is (or is ***not***) significant in the context of the exercise, and judgement about what is (or is ***not***) important in the context of the exercise.	Students must decide what to include or omit from a formal written report. They are given the demonstrator's assessment and feedback *pro forma*. They are encouraged to seek help from the demonstrator.	There must be sufficient data, details and discussion in the main body of the report, so that a student (classmate) who has done everything as the student writer, except this exercise (or this unit), can understand the report.

Scientific and Practical Skills

Students should be able to operate a simple spectrophotometer.	Students prepare sample solutions and use the spectrophotometer to make measurements.	Spectrophotometer will be within the expected ranges (ie **not** off-scale). Students will record consistent measurements. Linear Lineweaver-Burk plots will result from proper use of the instrument when the proper "blank corrections" have been made.
Students should be able to handle light-sensitive reagents.	Students will protect reagents and sample solutions from light.	Students will record measurements at the end of the exercise (eg test-tubes 10, 11, 12) that are consistent with measurements at the start of the exercise (eg test-tubes 1, 2, 3).
Students should be able to use a spreadsheet package to collate, display, and analyse observed data.	Students will use a spreadsheet package to collate, display, and analyse observed data.	Students will obtain linear Lineweaver-Burk plots, similar to those in the student notes.

Generic Skills

Students should be able to work in teams, and to plan and manage their time effectively.	Students must divide tasks between themselves at different stages of the laboratory exercise.	Students will complete the allocated tasks with minimal conflict.
Students must be able to use and interconvert units correctly.	Students should be aware of and convert between molar (mol L^{-1}) and millimolar (mmol L^{-1}) quantities.	Students should be aware of and convert between molar (mol L^{-1}) and millimolar (mmol L^{-1}) quantities.
Students should (further) develop communication and generic skills (*24,25*), including the ability to use appropriate computer programs (*26*). *Note: The semester-long physical chemistry laboratory program at Deakin University is one of a series of laboratory programs specifically intended to foster report-writing skills. Students are given the opportunity to submit draft reports for comment. This aspect of the curriculum is not an integral component of the current exercise.*	Students are given the opportunity to submit draft reports for comment. Students are encouraged to consult their demonstrator on the report writing style and use of appropriate computer programs	Students will present a formal written report, which satisfies the criteria set out on a assessment and feedback *pro forma*.
All of the above knowledge and skills	By preparing a clear, well-structured formal report, students will organise their knowledge and understanding and to consolidate learning (*27*)	Students demonstrate that their knowledge, skills and understanding … satisfy the stated and implied criteria and they have met [or exceeded] all the other requirements … *Note: This criterion is an extract from the Faculty guidelines on grading and assessment. It is clearly communicated to students during the semester and is the basis for assessment of all laboratory exercises and assignments.*

Section 3 - Student Learning Experience

Explainatory notes to Student Learning Experience

In response to student feedback in 1999 and 2000, the exercise was revised (*28,29*) and presented to the APCELL workshop (*30*) in early 2001. The exercise and associated documentation was again revised, incorporating suggestions from workshop participants. The student responses in this section document improvements to the exercise over the last 2 years (S1-4, 2000; S5-8, 2001). The version presented here includes further changes in response to the 2001 student feedback, and to comments from the APCELL referees. In the following responses, omission of a particular student (eg S7 and S8 for question 3.2) indicates that the student did not respond to that particular question.

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

S1: Yes, gives practical example in which the observed occurrences aid understanding.

S2: No, not easy to understand the kinetics. Therefore didn't understand final results.

S3: Yes, a little. I got values and I know what these values mean but concepts where a little hard to understand at first.

S4: Yes, it demonstrated how Michaelis-Menton kinetics can be applied to enzyme activity.

S5: I personally struggled a little with the concepts and theory involved. I think this was partly due to my very limited background in biology/ biochemistry.

S6: Yes, the write-up helped me understand the theory.

S7: Yes, it overlapped Biochem A from last term, but in more depth

S8: Yes.

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

S1: Enzyme kinetics isn't my major area of interest. But it is good to be able to understand.

S2: Not very relevant.

S3: Not that relevant, but I do think it is interesting.

S4: It helps to increase my background knowledge of reaction kinetics.

S5: My planned major is environmental engineering. I feel some biochem may be useful for me.

S6: Kinetics is used extensively for chemistry in pyrotechnics and explosives development. *Note: This student had commented previously (in feedback for another exercise) that he wanted a career in pyrotechnics and explosives development.*

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

S1: Yes. understanding the principles behind the prac.

S2: Yes, it was interesting to observe the biological effects of catalysts and inhibitors and the effects they have on reactions.

S3: Yes, getting to use "real" food not just chemicals in jars was something different.

S4: Yes, it was good to use a potato instead of just chemicals.

S5: I find chemistry work much more interesting when it has a 'real world' relevance. Here we used potatoes and talked about bruising.

S6: Nope, sorry. Didn't find much at all interesting. Didn't appeal to me.

S7: In between! It had interesting things and boring things.

S8: Yes.

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

S1: Yes, there is time to reflect as the prac can be covered quite quickly

S2: Yes, there was enough time to complete the prac but when adding the inhibitor in one-minute intervals, it was difficult to reflect on what was happening.

S3: Yes, we had plenty of time.

S4: Yes.

S5: Yes & no.

S6: Yes plenty of time.

S7: Yes.

S8: Yes.

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

S1: Teamwork is required to ensure the experiment runs smoothly during analysis section. Working as a team is very beneficial as it can lead to quick and effective work.

S2: Not much teamwork was required, only when recording absorbances in one-minute intervals was it better to work with someone. This was beneficial as it allowed timing to be more accurate.

S3: Working in groups is usually more beneficial as you can discuss what is happening with team members and it speeds up the prac as you don't have to do all the boring pipetting yourself.

S4: Yes, to help understanding.

S5: Exp. definitely runs faster when working in a group.

S6: Yes. teamwork is needed to get the potato and enzyme ready in the right time intervals.

S7: Yes, teamwork for this experiment was beneficial.

S8: Yes — In order to make it a quick and easy experiment.

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

S1: Yes, you have to take responsibility otherwise understanding of the topic will be harder.

S2: No, more focussed on getting good results.

S3: Yes, I had to do some research to understand the concepts.

S4: Yes.
S5: Yes, to an extent.
S7: Yes.
S8: Yes.

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

S1: Yes, there was a reasonable diversity of elements that needed to be understood.
S2: Yes, it incorporates a bit of biology with a bit of kinetics.
S3: Yes, because it is more Biochemistry / Biology related.
S4: It's kind of a bit of biochemistry mixed with physical chemistry which is good.
S5: Yes, it has biochem links to phys. chem concepts.
S6: I guess, student who had done biochem had a definite head start.
S8: Yes — chemical kinetics and biological reactions.

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

S1: Gives an adequate guide as to where to start.
S2: No. Not enough information was given on K. The notes showed what to expect, but not how to get there or how to interpret results.
S3: Yes.
S4: Yes, the laboratory notes were very helpful.
S5: Yes, although demonstrators explanation was important for my understanding.
S6: Yes. they were my only reference. Very good notes.
S7: Yes.
S8: Yes.

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

S1: No.
S2: Relatively simple experiment but the theory behind it not well understood.
S3: The manual should more clearly explain how Abs is related to Rate. It was unclear how to interpret results to start off.
S4: The results did not work which was a bit of a drawback.
S5: I found the procedure for calculations a little confusing. I wasn't sure what to do with results. ie: Abs a c
S6: The calculations, write-up, and plotting of graphs takes way too long.
S7: None.
S8: To much theory on enzyme kinetics to learn that I didn't know of.

3.10 What improvements could be made to this experiment?

S3: A little more about K_I could be included in the theory section.
S4: The actual experiment could be enhanced to facilitate good results.
S5: More detail related to calculations in method or introduction.

3.11 Other Comments

No comments were received from students for this question.

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One-to-one comparison for the teaching of amount balance and the dimension of the mole

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Abstract

An arrangement of elementary entities, hereafter called an entity sheet, makes amount balance clear in both stoichiometry and chemical substance. This sheet shows that the principle of comparing one chemical amount with another is one-to-one correspondence, by which the dimension of 'amount of substance', including the mole, is constructed. Using this approach, students in learning the mole could overcome the confusion between number counting and one-to-one correspondence.

One of the difficulties in teaching the mole is a gap between the atomic/molecular (microscopic) and the chemical substance (macroscopic) worlds. To bridge the gap, Ainley[1] and Nelson[2] firstly emphasised that the mole is a physical quantity (not a number counting unit), and secondly used the method of *N*-times to introduce the mole. A stoichiometric equation

$$C + O_2 \rightarrow CO_2$$

is given, in which one carbon atom reacts with one oxygen molecule, producing one carbon dioxide molecule. This is a phenomenon in the atomic/molecular world. "What can happen once, can happen *N* times," they said. Then, *N* atoms of carbon combine with *N* molecules of oxygen, yielding *N* molecules of carbon dioxide. This is an occurrence in the macroscopic world of chemical substance. A proper choice of the number *N* leads to the mole expression of the three chemical substances. The method of *N*-times bridges the two worlds. However, in such a derivation procedure one cannot determine the dimension (class) of chemical amounts and the mole, and hence chemistry teachers cannot clear students' misunderstanding[3] such that the mole is a number counting unit.

One-to-one correspondence

One-to-one correspondence is a commonplace concept which people use in everyday life. Let us imagine the following situation: When a pupil returns home no one is there, but he/she finds three cups of tea on the kitchen table. The pupil could obviously infer that there were three persons in the room earlier, because of the correspondence between cups and persons. The same conclusion might be reached by counting numbers because the number in the example is very small. It should be noted that the two concepts, one-to-one correspondence and number counting, are often confused.[4]

Now let us image another example, metal nuts and bolts. This example in textbooks has often been treated by number counting; however, nobody can apply the operation of number counting to the atomic/molecular world in chemical reaction, because the order of the numbers is extremely large (about 10^{23} for 12 g of carbon-12). Note that the following discussion makes no use of number counting.

Three bags are given. The first bag, called N hereafter, contains nuts, and the second, B, bolts. The third bag, called NB, is empty. An operation is defined as follows: take a nut out of bag N, and also a bolt out of bag B; then screw them together, and place into bag NB. This operation can be written as the symbolic equation

$$N + B \rightarrow NB$$

which looks like a chemical reaction. One repeats the operation from morning till night. Suppose that the two bags, N and B, become empty at the same time. Then one can say that the amounts of items in the three bags are the same, and can thus write

$$n(N) = n(B) = n(NB)$$

where *n* stands for the amounts. Here one might comment that in the definition of the operation it is simpler for students to use the name of the bags and the symbol of the nuts and bolts in different notation. In chemistry, however, the name of a chemical substance (*e.g.*, carbon) often coincides with its elementary entity (*e.g.*, C). Hence, the naming of the nuts and bolts follows the usage of chemistry.

Balancing chemical amounts in chemistry

One-to-one correspondence in the example of nuts and bolts was performed by hand. On the other hand, in the chemical world, reaction corresponds one elementary entity to another.

Now reconsider the chemical reaction

$$C + O_2 \rightarrow CO_2$$

in the atomic/molecular world. Chemists regard this equation as representing the stoichiometry among three chemical substances, carbon solid, oxygen gas and carbon dioxide gas. The chemical substances can thus be expanded in row form as

{ C C C ... C }

{ O_2 O_2 O_2 ... O_2 }

{ CO_2 CO_2 CO_2 ... CO_2 }

Such an arrangement of elementary entities is referred to as a chemical entity sheet or simply an entity sheet.[5] Here one row { . . . } stands for a chemical substance, and each symbol in the rows indicates an elementary entity. In every column an elementary entity corresponds to another; hence the amounts of the three substances are the same. The equality can then be written as

$$n(\mathrm{C}) = n(\mathrm{O_2}) = n(\mathrm{CO_2})$$

which shows amount balance in stoichiometry. Observe the similarity between producing carbon dioxide gas and packing nuts and bolts.

In the stoichiometric equation

$$2\mathrm{H_2} + \mathrm{O_2} \rightarrow 2\mathrm{H_2O}$$

two hydrogen molecules react with one oxygen molecule to produce two water molecules. Then the entity sheet is expressed as

{ $2H_2$ $2H_2$ ... $2H_2$ }

{ O_2 O_2 ... O_2 }

{ $2H_2O$ $2H_2O$ ... $2H_2O$}

This one-to-one relationship between elementary entities in the row sets gives the amount balance

$$n(2\mathrm{H_2}) = n(\mathrm{O_2}) = n(2\mathrm{H_2O})$$

Here $2H_2$, O_2, and $2H_2O$ are elementary entities.

Further expansion of the row sets leads to the new entity sheet

{ H_2 H_2 ... H_2 | H_2 H_2 ... H_2 }

{ O_2 O_2 ... O_2 }

{ H_2O H_2O ... H_2O | H_2O H_2O ... H_2O}

Half the amount of the chemical substances, hydrogen gas and liquid water, is equal to the amount of oxygen gas. Hence one has the amount balance

$$n(\mathrm{H_2})/2 = n(\mathrm{O_2})/1 = n(\mathrm{H_2O})/2$$

A more generalised form in stoichiometry is written as

$$a\mathrm{A} + b\mathrm{B} \rightarrow c\mathrm{C} + d\mathrm{D}$$

Here each letter in the upper case stands for an elementary entity. The entity sheet suggests the amount balancing

$n(a\mathrm{A}) = n(b\mathrm{B}) = n(c\mathrm{C}) = n(d\mathrm{D}) = n(\mathrm{A})/a = n(\mathrm{B})/b = n(\mathrm{C})/c = n(\mathrm{D})/d$

Let us consider amount balance in a chemical substance, *e.g.,* methanol. In this example, a methanol molecule includes, *i.e.,* corresponds to, one methyl group, one hydroxyl group and four hydrogen atoms. One-to-one correspondence no longer needs the entity sheet for methanol, probably. Thus, one gets

$$n(\mathrm{CH_3OH}) = n(\mathrm{CH_3}) = n(\mathrm{OH}) = n(4\mathrm{H}) = (1/4)n(\mathrm{H})$$

Note that the last equality is derived from one-to-one comparison between rows{ 4H 4H . . . 4H} and{ H H . . . H}. The amount balance in a chemical substance with an elementary entity B is given, in general form, by

$$n(\mathrm{B}) = x\, n(x\mathrm{B}) = x\, n(\mathrm{B}_x)$$

where *x* is a positive integer or a positive fraction.

Introducing of the mole and the dimension

The previous discussion did not refer to the unit of 'amount of substance'. SI (the International System of Units) defines[6] the mole as: the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kg of carbon-12. This statement implies that the molar mass of carbon-12 is equal to 12 g/mol (exactly); *i.e., M*(^{12}C) = 12 g/mol (exactly).

Let us add to the entity sheet the row set

{ ^{12}C ^{12}C ... ^{12}C }

which is an expansion of the chemical substance ^{12}C. The amount of the row set 12 g of ^{12}C is just the mole. One fraction of one thousandth of the row, or 12 mg of ^{12}C, is denoted by mmol; 1000 times as long as the row, or 12 kg of ^{12}C, stands for kmol.

The amount of a given chemical substance, for example, oxygen gas, in the formation of carbon dioxide can now be measured by means of the mole. Put the mole (the row of ^{12}C) on the row of oxygen gas, and perform one-to-one correspondence between elementary entities. If the oxygen gas is, for example, one half of the mole, one can write this situation as $n(\mathrm{O_2})/\mathrm{mol} = 1/2$, *i.e.*, $n(\mathrm{O_2}) = (1/2)$ mol. The procedures for the use of the mole and that for the yard stick are the same. The mole and *n* are physical quantities.[6] However, no one can observe directly such a procedure of measurement in the chemical world because one-to-one correspondence only occurs in the atomic/molecular world.

If $n(\mathrm{O_2})$ is equal to $n(^{12}\mathrm{C})$ in the two rows of ^{12}C and O_2, one-to-one comparison implies that

$$M(\mathrm{O_2})/M(^{12}\mathrm{C}) = A_r(\mathrm{O_2})/A_r(^{12}\mathrm{C})$$

where A_r is the relative atomic/molecular mass (determined by, *e.g.*, mass spectrometry). The IUPAC definition[7] is given by $A_r(^{12}\mathrm{C}) = 12$ (exactly). Hence one has

$$M(\mathrm{O_2}) = (12\ \mathrm{g/mol})A_r(\mathrm{O_2})/12 = A_r(\mathrm{O_2})\ \mathrm{g/mol}$$

It is clear that the elementary entity O_2 in this equation can, in general, be read as B. One can now measure mass for oxygen gas, for example. Let $m(\mathrm{O_2})$ be such mass. Then balancing molar mass leads to

$$m(\mathrm{O_2})/n(\mathrm{O_2}) = M(\mathrm{O_2}) = A_r(\mathrm{O_2})\ \mathrm{g/mol}$$

which gives $n(\mathrm{O_2})$.

It should be noted that apparently different physical quantities (amounts) in the entity sheet are identified by means of one-to-one correspondence. The amount balance in the entity sheet suggests the existence of a dimension concerning amounts of substance because a dimension is a set of entries which are regarded as the same under some principles.[8] The dimension of 'amount of substance' is now expressed as

[amount of substance] = { n(C), $n(O_2)$, $n(2H_2)$, $n(CH_3OH)$, $n(^{12}C)$, mol, mmol, (1/2) mol, . . .}

The origin of misunderstanding the mole as a counting unit may reside in the expression, ". . . as many elementary entities as . . . ," in the SI definition. There may be attempts to define the mole, which have no expression with relation to numbers. One example is as follows: The mole is the amount of substance of an elementary entity that has one-to-one correspondence to an atom in 0.012 kg of carbon-12.

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Contemplating Change: A Journey of Reflection Towards Action

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Abstract

This paper reports on the effects of a professional development initiative with twenty university chemistry faculty in the Department of Chemical Engineering, Nacional Universidad del Litoral, Santa Fe, Argentina. A workshop over four weeks was conducted with the purpose of producing a cohort of reflective practioners who were committed to undertake action research into their own praxis. A model of human action guided the structure of the workshop that analysed four contributing influences known to contribute to the *raison d'etre* of professional practice. These influences are defined as public knowledge, personal practical knowledge, worldview and praxis.

The workshop required participants to develop action research proposals consistent with the four dimensions above. Participants were given the opportunity to discuss a range of innovative practices in chemical education as well develop appropriate research methodologies to investigate educational aspects of their classrooms. The ability to plan, act, observe and reflect were the key attributes of the action learning cycle for the participants.

The effects on the participants after four weeks of workshop activity are discussed. The participants were also interviewed two years later for evidence of change in classroom practice. Analysis of the findings against the current literature on personal change is also provided.

Introduction

This paper reports on the challenges faced by a group of twenty professors of chemistry and chemical engineering who volunteered to undertake a professional development course designed to facilitate the process of change in their classroom practices. This course was designed and delivered to give participants the opportunity to analyze their own practice.[1] The goal was to produce reflective practitioners who would choose to act in a way that would produce different learning environments for their chemistry classrooms.

Understanding the Actions of Professionals

Much of the professional development of teachers at all levels of the educational hierarchy has assumed the 'teacher as technician' model. That model denies many of the developmental needs of the professional teacher. The adapted perspective for this course substitutes a 'moral order' for the 'causal-technical order' within which much development is traditionally set. [2]

This section outlines an analytical framework for the study of the interactions between knowledge, values and practices within the professional development process. The essential features of a model of human action are displayed in Figure 1 and place the elements within two background contexts: the self in relationship with the social context.

Reflection is at the centre of the model and is the open, active communications channel between the social context and the inner self. Reflection is an evaluative dialogue that enriches the self and enhances professional practice. Reflection can act as a forum for the decision making that results in considered action in the teaching context.

It is hard work to hold these internal debates. They require time and energy just to conduct them. And if we take them seriously, we usually find ourselves being urged to take the more difficult path, the path of more effort rather than less.[3]

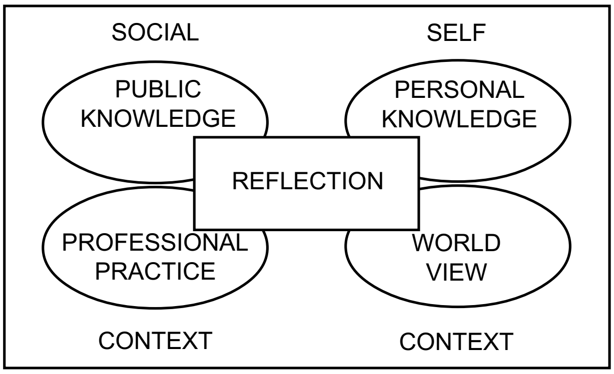

Figure 1. The elements of the Butler model of human action

Public knowledge includes all that the teachers interact with in the form of theories, formal knowledge, policy directives, research results, hints and folklore, community and student expectations. Public knowledge is a very visible and clamorous component of this model. It attempts to mould and control the professional practice of the teacher.

Professional practice of the teacher is the human action itself. This occurs in the social context when teachers have to make decisions and act according to their responsibilities. This informed action requires the teacher to understand the salient features of the situation. The model assumes that professional practice is more deeply expressive of the self than of external public knowledge.

Worldview is the individuals own way of looking at the world derived from tradition and culture and is therefore historical and contextual. World view contain a mixture of rational and irrational beliefs, some contradictory assumptions, and a tablet of values and rules that the self holds as true at this stage of its development. The worldview provides stability but to be effective must be continuously revised through careful and detailed self-examination.

Personal practical knowledge is a store of knowledge and understanding attained through lived experience and is enriched through wider and more vivid experiences and can be transformed by paradigm shifts in understanding. This conscious and unconscious personal knowing is the 'tacit knowledge' that has been shown to exert a powerful influence on performance. The personal practical knowledge that is required for personal and professional development cannot be extended systematically and justification of one's personal practical knowledge must appeal to courts other than the courts of reason or strict rules or method. Rather the justification is historical or contextual; the knowledge is excellent now for this context, it is designed for the how and the now.

The personal practical knowledge that is gained is about trusting the self to perform, to trust what one already knows, to be authentic in all ways, to value and use that which has been derived from action and led to fruitful action.

Towards Action:

A Journey of Personal Redefinition

The design and the presentation of this course were focussed on attaining an outcome, which brought about reflection-to-action in the context of university chemical education. This reflection-to-action would need to overcome the mental obstacles that hinder change and enhanced practice. Many of the real obstacles are self-imposed. Modification of professional practice requires individuals to alter deeply rooted, self-defining attitudes, values and beliefs. The personal redefinition that this involves is likely to be slow, stressful and sometimes traumatic.

Two well-known characteristics of human action are: the certainty of human action is never equal to the immediacy of action; and that human action always gives rise to unintended consequences. Both of these features offer opportunities for teachers to learn from undertaking deliberate and carefully designed practice. The choice of what to do is the beginning rather than the end of the processes of justification and reflection.

This introduction to the model of teacher agency informs the remainder of the paper on teacher professional development.

Action Learning as the General Learning Model

Action learning models are widely recognized as one of the most powerful ways of assisting people to learn in the workplace and to change the culture of the workplace. The complete action-learning model requires several formal journeys around the action-learning loop with outside assistance. This action learning training model has cycles composed of the four processes:

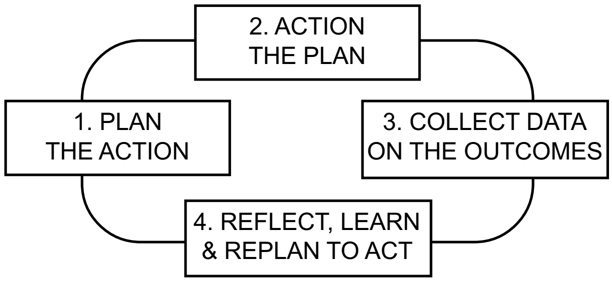

Figure 2. The Action Learning Cycle

Action learning is also very powerful in creating a culture of lifelong learning. The participant in an action-learning project that is designed to progress several times around the loops is often given strong motivation by the self-reinforcing effect achieved by the definite, visible and deliberate learning that is achieved. The expected outcome therefore is that the participant continues the action learning loops long after the program implementation has been finalized.

Action learning has the following key characteristics:

- it involves learning by doing
- "doing" in this case implies a project
- the project is not artificial but involves an actual development in the department
- the project is undertaken in a systematic and analytical way and the evaluation of progress and success is built in to the project work
- all participants undertake a systemic analysis of what they need to learn to complete a project, and, later what they have actually learned from completing the project
- this systematic analysis of learning, conducted in parallel with the projects themselves, is crucially undertaken as a group activity, even if projects themselves are completed by individuals

The Public Knowledge Dimension

of Chemical Education

A volume of course readings was distributed to participants a month in advance of the commencement of the course. These articles were representative of current theory and practice (public knowledge) - about learning, teaching and the assessment of chemistry. Additional resource materials related to research methods in education, provided background knowledge and procedures for the conduct of action research.

The background readings, however, provided a broad guide. What participants actually planned to do was just as dependent on the understanding of the practical circumstances surrounding their own teaching environments and their own creativeness. These practical aspects helped modify the perspectives represented in the literature. But given their realities, it was easy for all the participants to lose sight of the theory. It was therefore all the more important to use the original or modified theoretical notions as the basis of reflection and as a source of criteria for the evaluation of one's own practice.

Course Outline: Topics and Sequence
Week 1

1. Introduction: Making Meaning of Action Research and Personal Change
2. Problem -Based Learning
3. Chemistry Education: Where to now?
4. Review of Related Literature

Examples of the literature in chemical education (Public Knowledge) were provided in advance as part of the course readings. These can be classified under the following headings:

A. Knowing Chemistry
B. Teaching and Learning
C. Teaching and Learning About Chemical Change
D. Teaching and Learning About the Particulate Nature of Matter
E. Teaching and Learning About Stoichiometry
F. Teaching and Learning About Chemical Equilibrium
G. Assessment of Thinking Skills and Conceptual Understanding
H. Problem Solving
I. Language and Learning of Chemistry
J. Information Technology
K. Microscale Chemistry
L. Chemistry Curricula for Non-Science Majors
M. Gender Issues in Chemistry Education

Week 2

5. Defining the Research Problem and Identifying the Research Questions
6. Developing the Research Methodology
7. Exploring Techniques to Gather the Data
8. Selection of a Sample Population

Weeks 3/4

9. Developing a Research Proposal
10. Discussion of Proposals

The Design of Adult Learning Environments
Learning settings that encouraged participative, democratic processes based upon values of collaboration and interdependence were adopted. In terms of managing and of learning, empowerment - the sharing of power, knowledge, information and authority was an essential characteristic of the workshop environment.

The adult learning principles that influenced the conduct of the course were:

a. Adults have a need to know why they should learn something.
b. Adults have a deep need to be self-directing.
c. Adults have a greater volume and different quality of experience than youth.
d. Adults enter into a learning experience with a task-centred or problem-oriented or life-centred orientation to learning.
e. Adults are motivated to learn by both extrinsic and intrinsic motivators.

This journey using action research techniques and personal reflection on one's praxis allows practitioners to innovate in a way that allows movement

from
"knowing that" - the cognitive mastery of the theoretical basis or rationale of processes
to
"knowing how to", the cognitive mastery of processes
to
"being able to" - successful use of processes in practice.

Reflection-to-Action
Data were collected from the participants over the 4 weeks of the course (40 hours of formal class contact time). This data consisted of statements written by each participant during "free write" opportunities. The guidance given to the participants was as follows:

"Write about your thinking and your feelings on the issues raised in the course so far as well as the personal challenges which may have emerged."

Participants were asked to submit these "free writes" anonymously in Spanish or English.

Participants' Reflective Writing: Week 1
A sample of these writings is presented below:

"I have a lot of questions and expectations... the problems raised by the course introduction, I feel I recognize these in my classes also "

"I am interested in changing my ideas and attitudes about teaching"

"My experiences with this type of course are very limited. My colleagues do not normally talk about the problems of learning and teaching... I need to know other points of view to have the power to make proposals although they may not be very practical "

"All of us need to reflect about our classes... I don't understand all that I hear but I will try to make use of this new knowledge"

"Ideas from other countries are interesting but we need

to self assess our actions"

"We need to look inside ourselves to find the desire to teach differently... the course gives us the legs to allow us to advance"

Participants' Reflective Writing: Week 4

"To look into one's self is not an easy homework assignment because we find things that we do not like and some things that we do. This course gave us the time to pause and reflect. This gives us insights, which permits us to grow- even a small amount. I have much to learn through the investigations within my own knowledge and my students"

"I feel that the course has opened new perspectives about teaching, learning and assessment in chemistry. The homework provides areas for investigation. I am not able to perform to the desired extent at this time and I will need help and more experience with education and the implications for teaching the subject matter in chemistry. Although my aims are very clear I need to do more investigations of the literature. I assume I can make the changes using the action research plan. My work environment is strongly scientific and this plays against research in education. I feel that all the efforts will not be reflected in the learning of chemistry students even though my decisions are well intended. I can't rely on any others with a similar view as they are not interested in more learning outcomes in chemistry. People are more interested in self rather than student learning. The lack of the generalization of educational research findings worries me"

" It is useful to focus on the situation from the students' perspective. To reflect and act to encourage student learning from context to concept will be worthwhile"

"The course allowed me to organize my ideas. Although I have applied many of the points in the course I believe I can now organize my course better. The real learning from this course will be demonstrated when I put into practice a new idea and I evaluate the result"

"I feel the uncomfortableness of having to change. The course has had the effect of knowing I have to change. I need to complete an implementation and see how it will work"

"I have become aware from the information presented in the course. I am now informed about different teaching approaches. I was unaware before"

" I believe what I have learned will be useful. I will try to apply these ideas so I can introduce change, which favourably enhances student understanding. I am conscious of the need to bring about change and now I have ideas about how to change "

"The course impacted positively because it empowers the professor to make changes in the teaching and learning. It forces one to think about the design of new techniques with the objective of awakening a love of learning "

" I found more clarity in the relationship between the topics than before. I only understood it intuitively before. I need to review and reflect about the relationship between the lab and the lecture classes so that I can communicate better with my students

And Two Years Later

"I have tried to implement some changes in the field of Inorganic Chemistry, particularly about how students learn and what are the systematic mistakes they make. I also tried to make the classes more integrated (lecture, lab practices, etc), integration of teacher thinking and student thinking, trying to explore more deeply what students really think (or they believe they think). I felt totally free (from an institutional point of view) to do this"

I'm currently conducting the research on the impact of technologies but not as systematically as I would wish. Some outcomes (preliminary) have been very encouraging. Students have responded well; my communication with them is satisfactorily improving, but there is much more to do. I feel very comfortable doing this primarily because my students and I need it. My perception is that students are moving towards better learning. I think the changes I am trying to make are possible"

"It is difficult to change because there are a lot of students and a lot of subjects to teach. The work is very individualistic for the teacher and there is no assistance to resolve the administrative problems"

"It has been difficult to change because of the lack of humility to recognise what we don't know as well as the lack of stability (political, institutional goals etc)"

My attempt to change has not been easy. There are no rules or the rules keep changing. We don't know where we will be working or whom we will be working with next semester. We need money to research and to get technology"

Making Sense of Attempts at Personal Change

Educational innovation at any level is always fraught with difficulty and uncertainty. In this particular instance the month long workshop to encourage university teachers of chemistry to reflect-to–act so as to develop an action plan was, for the majority of participants, partially successful. The ability and the commitment to reflect about their practice in line with Butler's model in Figure 1 was always going to be the major challenge for such professional development. The development of personal action plans, although incomplete in the majority of cases, was one of the more favourable outcomes of the workshop.

As stated in the 'free-writes" selected above the intellectual journey over the one month of the workshop was characterised by personal reflection about their current practice. There was evidence of movement from the position of "knowing that," the cognitive mastery of the theoretical basis or rationale of processes to "knowing how to", the cognitive mastery of processes. However with a few exceptions that is where the action stopped. In a return visit to the University two years later, the situation was one of disappointment on the part of the professional development providers and desperation on the part of the university staff. The personal actions of staff, characterised by being able to use the processes in practice, was evidenced in only three of the original twenty participants.

A selection of the reasons as to why this took place is provided above.

The challenges associated with change in educational environments has been researched extensively.[4,5,6] Findings from such research place some light on this particular set of events. Two important points seem particularly relevant to the two-year data. The first point is that the management of change requires the power to do so.[7] In all of the negative examples quoted above reference was made to circumstances external to themselves that mitigated against their willingness to act differently. These circumstances were to do with departmental administrative constraints; university rules governing student entry standards and national economic conditions leading to job insecurity. Most of these respondents indicated that to attempt change during these uncertain times would place their professional lives at risk. This was understandable given that the majority of the staff attending this workshop was not senior academics in the department. On the other hand these concerns may appear on the surface to be based on irrational beliefs about change and professional risk. Only further debriefing of the participants' worldviews would reveal the true basis of these stated concerns.

A second point emphasized in research findings is that resources are the appetites of change.[8] In an economically deprived department this is indeed a major issue and seems to be reflected in this particular case with many participants pointing to the lack of technological and administrative support. Change does require additional resources for new materials and for time. Time is energy and time is money. Good resourcing abjures any false pride about self-sufficiency and it requires nous to go outside the normal framework in reallocating available resources.

In Conclusion

This project was essentially about a professional development initiative that would encourage university teaching staff in chemistry to reflect-to-act. The four-week workshop provided the catalyst for this personal reflection to be undertaken and the evidence was provided in the personal action plans of most of the participants. For some this four-week period proved to be very challenging. Teaching and learning were viewed as non-problematic. Issues raised during the course to do with student learning of chemistry were seen as issues for students not for teaching staff. Therefore the challenge to reflect-to-act resulting in a personal action research proposal about their praxis proved to be insurmountable. However the workshop did result in the production of action research plans and as such provided the platform for the next step – to investigate some aspects of their personal praxis.

The failure of most of the participants to continue with their action research proposals over the following two years proved to be disappointing. This failure to "institutionalise" the planned changes in personal practice is consistent with earlier research findings that suggest that change is a journey not a blue print and that change is loaded with uncertainty. Rational planning models of social change do not work; rather it is a guided journey where strategy is viewed as a flexible tool, rather than a semi-permanent expansion of their mission. Anxiety and difficulties are intrinsic to all successful change as innovation represents new personal meaning and new learning.

The following comment is an appropriate epitaph for this project which commenced with good intentions and commitment by the staff but for many, economic circumstances unimaginable in most western countries became overwhelming for the whole society at large.

" I can't change very much because of the economic instability of the country, the strong structure of the university, poor integration of the areas in the department and the shallow background of the students allows a narrow range of new actions in the time we have with them"

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Visualisation and Mental Manipulation of Molecular Structures

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Abstract

An investigation of three-dimensional visualisation abilities of tertiary chemistry students and faculty has been conducted using interviews. Participants were asked to decide whether two representations of a stereocentred molecule are identical or enantiomers. It was found that (i) there are considerable differences between the abilities of students to do these tasks, and (ii) each student and faculty member consistently employs an idiosyncratic strategy. There is a wide variety of such strategies, some of which are quite surprising. Explanations that teachers use may be inconsistent with the idiosyncratic approaches of their students.

Introduction

Understanding the three-dimensional arrangement of atoms in molecules is fundamental to learning chemistry. So it is of some concern that anecdotal evidence from chemistry lecturers at the tertiary level suggests that many students experience difficulty when interpreting two-dimensional representations of the three-dimensional structures of molecules.

It is common for lecturers to use blackboard or OHP drawings to teach about stereochemistry, perhaps assuming that the students visualise the representations in the same way the lecturer does. Organic chemistry textbooks contain many drawings, such as skeletal structures, space-filling models and Newman projections, and students need to be able to construct and mentally manipulate three-dimensional images from these drawings to understand the text (Pribyl & Bodner, 1987). While there has been much interest in the relationship between generic spatial ability and achievement in chemistry courses (for example, Carter, LaRussa & Bodner, 1987; Coleman & Gotch, 1998; Friedel, Gabel & Samuel, 1990), very little is known about the abilities of tertiary chemistry students to visualise the spatial arrangements of atoms in molecules.

Tuckey, Selvaratnam and Bradley (1991) used "elementary items", which test for just one visualisation skill, to diagnose the origins of student difficulties when visualising three-dimensional structures. Prior studies had not been able to identify the sources of students' difficulties, because the researchers tested for overall competence in three-dimensional thinking tasks. Tuckey et al. report that the majority of students had difficulty in making use of the depth cues on a representation of a three-dimensional structure, and in visualising the position of the atoms after rotation or reflection. These workers used generic representations of molecules, with substituents A, B, C and D, rather than specific substances.

This Study

The research reported here comprised part of a wider investigation of stereochemical visualisation abilities of undergraduate chemistry students, which included assessment of skills such as

- the ability to imagine the three-dimensional structure depicted by a representation
- the ability to imagine the structure represented by a diagram from a different perspective and to draw a diagram 'seen' from that new direction
- the ability to mentally rotate a structure represented by a diagram and to depict the result with a drawing
- the ability to decide whether drawings of two stereocentred molecules of the same substance are identical or non-superimposable mirror image enantiomers.

The focus is on the variety of approaches that can be used to undertake a particular stereochemistry task that requires visualisation of the three-dimensional structures of molecules represented by diagrams and mental manipulation of the imagined structures.

The tasks involve simple stereocentred molecules in which the central carbon atom is bonded to four different substituent groups. In particular, the tasks require the student to compare two representations of stereocentred molecules, each with the same four substituent groups, to decide whether they are identical or enantiomers. This is not immediately obvious, as illustrated in Figure 1.

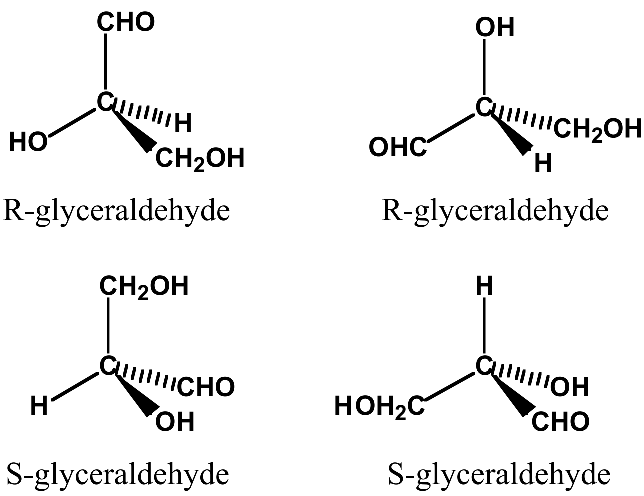

Figure 1. Recognition that the two molecules of *R*-glyceraldehyde are identical, that the two molecules of *S*-glyceraldehyde are identical, and that the two *R*-glyceraldehyde molecules are mirror images of the two *S*-glyceraldehyde molecules is not possible without mental manipulation of the three-dimensional structures imagined from the representations, or the use of short-cut strategies.

During individual and small-group interviews, students and lecturers were given tasks such as that shown in Figure 2.

Alanine: Are these mirror images or superimposable?

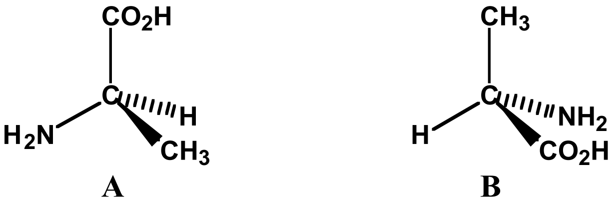

Figure 2. An example of problems used to evaluate student visualisation abilities.

This van't Hoff style of representation was deliberately chosen to direct the students' attention to the tetrahedral arrangement of the substituent groups around the stereocentre. Other ways of representing the structure of alanine, such as Fischer or Newman projections, were regarded as inappropriate because some of the participants lacked familiarity with the conventions of their use. The use of this style of representation also avoids any difficulty that may originate from students' inability to identify the stereogenic carbon atom in other types of representation.

During interviews, students and lecturers did not have access to molecular models. We have found that when people are given molecular models, the task is usually solved quickly - presumably because it does not involve visualisation of the structure represented by a diagram, and particularly because it does not involve mental manipulations of the visualised structure. Our concern is with situations, such as those that most commonly exist during lectures, where students do not usually have models, and mental manipulation of imaginary three-dimensional structures is necessary for sense-making.

While a number of studies have documented gender differences in the abilities of students to visualise and mentally rotate imagined structures (Bodner & Guay, 1997; Halpern, 1986; Voyer, Voyer & Bryden, 1995), it was not an aim of this study to distinguish the students' abilities according to gender.

Results

Our findings indicate there a variety of strategies that students use to approach a task such as that in Figure 2. This is illustrated below by reference to selected students who exemplify the various strategies. Pseudonyms are used.

Amy was a first-year student who consistently did the type of task shown in Figure 2 by mentally manipulating her imagined structure of A to compare it with her mental image of structure B. She always manipulated structure A so that it had the same substituent at the top as structure B: that is, she rotated A so that it had the C-CH_3 bond in the same place as it appears in B. Amy was then able to determine whether A was the same as B or different from B by comparing the arrangements of the other three substituents. Amy comments on her problem-solving method:

> *I like to have the same one at the top, then it's easier for me to turn it around at the bottom. /... / You have to have the top ones the same or nothing looks the same. To me, anyway.*

Andrew, a first-year student, used a method that involved somewhat complicated logic. He drew the mirror image of structure A and then mentally manipulated B to see if was superimposable upon the mirror image of A. If it was, then he concluded that A and B were enantiomers. If B was not superimposable upon the mirror image of A, he concluded that B and the mirror image of A had a mirror-image relationship and so B and A were identical. He consistently used this strategy in a number of tasks.

Another first-year student, Allan, always used a particular strategy which compensated for his relatively poor ability to mentally manipulate three-dimensional structures. Allan would imagine looking along the H-C bond in each structure, and draw a two-dimensional representation of the three substituents that he would 'see'. He compared the arrangement of the three groups in each structure by checking whether a chosen sequence was clockwise or anti-clockwise. Allan explained his approach in the following way:

> *I can't visualise it as to turning and stuff like that. /... / I find it easiest just to look down one of the bonds to see whether the other three [substituents] are in the same order.*

Derek was a final-year student who, like Andrew, first drew the mirror image of structure A. He would then mentally manipulate structure B to see whether it is identical to A or to the mirror image of A. If B and A were found to be identical, the problem was resolved. If B and the mirror image of A were identical, he would conclude that A and B were mirror images. Derek described how he completed the task as follows:

> *... you've asked me if it's going to be a mirror image, so, of course, I'm going to do a reflection at some stage. /... / ... firstly do the reflection of one of them. /... / The aim then is to arrange for at least two of the groups attached to the other carbon [in structure B] to be orientated in the same way as two of the groups here [on the mirror image]. /... / ... with the carboxylic group and the hydrogen in the same orientation as in the mirror image of the first molecule /... / it becomes obvious to me that the amine group and the methyl group are orientated differently.*

Darryl's way of thinking about tetrahedral structures was to imagine them balancing on a single group with three groups coming up out of the plane of the paper. Darryl (a final-year student) manipulated both of the structures into an orientation from which he could compare them. Here he describes how he used his strategy to determine the relationship between the alanine structures shown in Figure 2:

> *D: ... draw them so that they look the same (re-drawing both structures). So basically you've got a tripod, with feet sticking in the air and bouncing on the hydrogen*

group. /... / So then they're the same molecule.

I: ... any particular reason why you have the hydrogen going into the page, and not something else?

D: ... it's arbitrary, the way I do it, you can put anything into the page, as long as it's consistent.

Final-year student Cary, who showed highly-developed visualisation skills, employed a method that was different from those of all other students. He was able to do the task mentally without drawing intermediate structures. He mentally rotated structure A around an axis that bisects both the CH_3-C-H angle and the CO_2H-C-NH_2 angle. From the researchers' experiences during the study, including interviews with lecturers, this seems to be a rather extraordinary ability. What Cary achieves by complex mental manipulations may require other students with lesser visualisation ability to do a number of rotations, drawing each of the intermediate structures as they proceed. Cary described his strategy in the interview:

... match this first one to this second molecule by having the methyl group vertical and the hydrogen /... / just to see if it is a mirror image, then finding it's not, rotating the molecule around 180 degrees, the 'oxylate' [CO_2H] and the amine [NH_2] are going to match up to the first one. Therefore it's superimposable.

In contrast to Cary's exceptional ability to visualise and mentally manipulate an imagined structure is that of Donna, a highly successful honours student in organic chemistry. During the interview, Donna described herself as having

... a lot of trouble doing three-dimensional visualisation, and I remember, in my exams, with pens and things, trying to do them. / ... / I know some people can just look at something and rotate it in their mind, but I just remember having different coloured pencils with different coloured matchsticks on the end, and I sit there in exams, going, trying to see what's going on. I just can't do it in my head.

Donna tried to use an approach similar to Allan's, as she describes:

I just kept redrawing the molecule, so that, looking along this bond each time, the amine to carbon bond, trying to get a different perspective of the molecule and comparing it to the other one that was supposed to be the mirror image or not the mirror image, or whatever.

Donna experienced considerable difficulty. Her lack of visualisation skills made the task very frustrating, as is evidenced here:

... Because I couldn't just sort of look at it and rotate it mentally. So I tried to redraw it, hoping it would eventually look like a mirror image or it would become definitely apparent that it was or wasn't, but it sort of never got to that point. / ... / I can't just pick it up and turn it around in my mind. / ... / I can never get it to the point where I can swap that, the carboxylic acid group, with anything. That's always at the top and I don't know how to ... That's really dumb, I should know how to do this. It's annoying. / ... / I just can't work out how to do it, how to redraw it, it's annoying me.

All of the lecturers interviewed during the study were experienced instructors whose teaching schedules ranged from first-year introductory chemistry for non-chemistry majors to third-year bio-inorganic and polymer chemistry courses. All of them acknowledged that there are many different ways of solving the problems, but each lecturer had a preferred method. Some lecturers preferred to use methods that are unlike any used by students and these are reported here.

Errol used shortcuts he had developed with his experiences in molecular symmetry to help him compare one of the structures with the other. He swapped the CH_3 and CO_2H groups on structure A, so they were in the same positions in both structures. Swapping the positions of two groups in a structure has the same effect as making the mirror image of the structure. Errol noted that the arrangement of substituents after the groups were swapped was different to structure B, so he concluded that the two alanine molecules must be the same.

Eric rotated structure B around the C-H bond and then compared the resulting structure with structure A. With all of the tasks Eric completed, he rotated around or matched that bond in the plane of the paper (C-H in structure B). He describes his strategy of using the bond in the plane of the paper as a "fixation".

Edward also had a fixed way of solving all of the first-year level problems he was shown. His method involved the use of the Cahn-Ingold-Prelog rules to assign the *R* or *S* configuration of each molecule. When he was asked to try to tackle the problems by mental manipulation of the structures (as a first year student might be expected to do), Edward usually tried to put the hydrogen atom behind the plane of the page as required by the Cahn-Ingold-Prelog rules, and then compared the order of the other three substituents. Using the C-H bond as his focus made it difficult for Edward when the structure was in an orientation that he did not find easy to manipulate so that the C-H bond was behind the plane of the page:

This hydrogen up in the air is a much harder exercise, I think. /... / I always find it easier to have the hydrogen, your group four, as a 'foot' rather than as an 'up in the air'.

Emmett consistently used a strategy similar to that of Allan, in that he reduced a three-dimensional task to a two-dimensional task:

I'll view it opposite the CH_2OH because it's behind the plane of the paper, and I'll go from hydrogen to carboxyl to amino. Go in an anticlockwise direction, yeah. Now if I view this from underneath, then hydrogen and carboxyl and NH_2 are also going to be in an anticlockwise direction. / ... / They're both anticlockwise. So they're superimposable. / ... / So I guess what I do each time is I visualise down a bond.

Unlike Allan, Emmett did not need to draw the two-dimensional arrangements of substituents.

Discussion

Two issues emerged from the interviews: the ease (or difficulty) with which interviewees completed the tasks, and the strategies that they used to go about the tasks.

While no formal test was administered to interview participants, it was observed that there were marked differences between the three-dimensional visualisation abilities of students. In contrast to reported evidence that success in chemistry is linked to spatial ability, the visualisation abilities of highly successful advanced students Cary and Donna appeared to be at opposite ends of the spectrum. It seems that Donna had learned strategies to cope with her lack of visualisation skills.

Before interviewing the lecturers, it had been supposed that most lecturers would have developed a common preferred way of tackling simple stereochemistry problems. The findings concerning the variety of methods used by lecturers, along with the variety of methods used by the students, confirms that most people have a particular preferred way of "seeing" stereochemical relationships.

The different approaches used by students and lecturers to complete a task like that shown in Figure 2 can be classified as follows:

1. One structure is compared with the other by mental manipulation of the corresponding three-dimensional images (e.g., Amy, Cary, Errol, Eric).
2. The structures are compared with each other after mental manipulation of both corresponding three-dimensional images (e.g., Allan, Darryl, Edward).
3. The mirror image of one structure (X) is created and this is compared with the other structure (Y) by mental manipulation of their three-dimensional images. Once the relationship between Y and the mirror image of X has been ascertained, logical deduction is used to determine the relationship between the structures X and Y (e.g., Andrew).
4. The mirror image of one structure (X) is created and then the three-dimensional image of the other structure (Y) is mentally manipulated to see whether it is the superimposable upon X or upon the mirror image of X (e.g., Derek).

Within each of these broad approaches, there are idiosyncratic differences of strategies. For example, strategies such as matching the top substituent of both structures, completing the problem by complex mental manipulations of imagined structures, swapping pairs of substituents on structures, and matching the structure so there are common bonds in the plane of the paper were all used by people classified as having a Type 1 approach.

We observed a number of students and lecturers, such as Allan and Emmett, who reduced the three-dimensional visualisation aspect of tasks to a two-dimensional issue. Either by mentally shifting their point of view, or by rotating and redrawing the structure, they would consider the arrangement of just three substituent groups around the stereocentre.

There have been many suggestions (Bishop, 1978; Burnett & Lane, 1980; Lord 1985, 1987) of teaching strategies to improve general visualisation skills, but specific strategies to assist chemistry students' visualisation of molecular structures are harder to find. Perhaps it might be important for students to practise not only translating diagrams into three-dimensional structures (as is often done) but also to practise drawing diagrams of molecular models (as is seldom, if ever, done). Rehearsing the transition between three-dimensional figures and two-dimensional representations may improve the students' abilities to 'see' the three-dimensional image in their mind without the aid of a molecular model.

It might be expected that students' abilities to solve problems such as those shown in Figure 2 would be enhanced by allowing students to use molecular models to do stereochemistry practice problems during tutorial or laboratory sessions. Combined with continued rehearsal of the transition between three-dimensional figures and two-dimensional representations, the students will be able to develop their own visualisation and mental manipulation skills. Rather than simply watching a lecturer use a molecular model or computer image to illustrate a point during class, students handling molecular models while doing problems can make their own choices about solving strategy and learn visualisation skills at their own pace.

Summary

The following findings, related to mental manipulation of structures of simple molecules with one stereogenic centre, have implications for chemistry lecturers and textbook writers:

- Students majoring in organic chemistry differ widely in their abilities (including both correctness and rapidity) to mentally manipulate and compare structural representations.
- Even academic staff in organic chemistry may display and acknowledge difficulty in mental manipulation of structural representations, and frequently use techniques that reduce a three-dimensional visual problem to a two-dimensional task. This suggests that three-dimensional visualisation is an inherent ability which is not easily amenable to improvement.
- Students use a wide range of strategies to compare different structures. Each student uses a consistent strategy from task to task. Any explanation used in a lecture situation will be at odds with the way that at least some students prefer to compare structural representations.
- Some students have preferences for the orientation of representation certain molecules, particularly in relation to the positioning of a hydrogen atom or a large substituent group.

Of course, the eventual objective is to improve the functional ability of students, but the case has been made that we should not presume too much of the visualisation abilities of students, nor of the strategies that students use to go about comparison of structures. For example, while lecturer Edward finds it *easier to have the hydrogen, your group four, as a 'foot' rather than as an 'up in the air'*, he may consistently use this orientation without being aware that students have their own different preferences. The same applies when a lecturer tries to demonstrate the enantiomeric relationship between two structures using his or her preferred approach.

Presumably with representations that do not have the stereogenic centre explicitly indicated, with more complex molecules such as those encountered in biological situations, and with molecules that have more than one stereogenic centre, the student difficulties might be exacerbated.

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Book Review *Carbohydrates: The Sweet Molecules of Life*

Robert V. Stick
Academic Press, 2001, 256 pp, ISBN 0-12-670960-2.

Despite the rather alluring title, this book is overwhelmingly concerned with the synthetic manipulations of carbohydrates. Stick makes this clear in his Preface. As such, however, the book provides an excellent treatment of the subject, with brief but informative coverage of the more biological aspects of modern carbohydrate science.

The work begins with a thorough treatment of the history of carbohydrate science, with Emil Fischer being a central character in this discussion. Entwined in this history are explanations of many of the commonly used tools and terms used in carbohydrate chemistry, including Fischer and Haworth projections, the furanose and pyranose terminology, mutarotation, the conformational descriptors of the cyclic forms of sugars and the anomeric effect.

The central chapters, being the bulk of the book, deal with synthetic aspects of carbohydrate chemistry. Useful background on many standard organic transformations, including oxidations, reductions, halogenations and the Wittig and Mitsunobu reactions is provided. A handy coverage of the use of protective groups also appears in this part. The formation of glycosidic linkages is canvassed in great detail, and excellent explanations of modern concepts used in carbohydrate synthesis such as "armed" and "disarmed", "torsional control", and "latent" and "active" are given and are subsequently used to explain synthetic results. Synthesis on polymers supports, combinatorial synthesis and synthesis with enzymes also get a mention.

The final chapters deal with the more biological aspects of carbohydrate science. While not claiming to be all-encompassing, these chapters provide a useful overview of modern developments in the area.

Throughout the book, Stick makes copious reference to the literature, including review articles, and clearly, as much as possible, tries to "give credit where credit is due". He writes in a familiar, informal style which, combined with a liberal sprinkling of witty quips and quotes, makes "Carbohydrates: The Sweet Molecules of Life" a highly readable and entertaining reference book. Students studying carbohydrate chemistry at third year and honours level, or those researching carbohydrate chemistry, will find this book very useful. It is an ideal text for honours courses on carbohydrate chemistry. Instructors teaching carbohydrate chemistry from first year University upwards will find this text ideal for placing the material they are teaching into a broader context, as it delves deeper into carbohydrate chemistry than the standard organic texts we use today.

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The word on chemistry

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Had I been born a few thousand years ago in ancient Egypt, I would have had reason to pay homage to an assortment of deities depending upon what my particular problem was at the time. The top spot in the theological pecking order was held by ***Amen***, also written as ***Ammon***. Various interlopers came along and installed their own deities, or merged with existing ones, resulting in e.g. an Egyptian ***Ammon-Ra***, a Greek ***Ammon-Zeus*** and Roman ***Ammon-Jupiter***. Whereas Ammon is said to mean the "***Hidden One***", Sanskrit-speaking Indus Valley dwellers spoke of a "***Sky Father***" or ***Dyaus Pitr*** which others subsequently altered to ***Zeus Pitr***, ***Zeu pitr***, ***Jupiter*** or just plain ***Zeus***. So, he was important.

A Roman temple raised to Ammon-Jupiter was apparently the site of a bit of old-world chemical tinkering with some local shrubbery and animal dung. One product, despite its derivation from animal dung, was thought of so much that it was sanctified with the name of the ***Salt of Ammon***, i.e. ***sal ammoniac***, now ***ammonium chloride***.

Jumping Jupiter you might say – well, don't. The overall meaning of ***dyaus*** extended from ***sky*** to that of ***day*** and gave us ***diurnal***, altered in French to talk of a ***day book*** called a ***journal*** (and a ***diary***), despite J. Aust. Ed. Chem. emerging somewhat less frequently.

We now know that ***ammonia*** is a compound of ***hydrogen*** and ***nitrogen***, with ***oxygen*** thrown in when in the ammonium form. When first described, these were uttered in French as ***hydrogene***, ***nitrogene*** and ***oxygene***, the ***-gene*** suffix relating to ***generate***, each describing some attribute of a product. ***Hydrogen*** was ***water-forming***, with ***hydra*** denoting ***water***; ***oxygen*** was ***acid-forming***, Greek ***oxys*** describing a ***sharpness*** of taste; and ***nitrogen*** was ***nitron-forming*** apparently due to the resemblance of its salts to the Greek ***nitron*** or Egyptian ***ntry***, a native hydrated sodium carbonate.

Now, ***water*** is a very common substance and the Romans seemed to have had a variety of names depending on what it was doing at the time. The term ***water*** convolutingly comes from an ***undulating*** Roman ***wave*** or ***unda***, but without reference to its location. For ***sea water***, Romans took their word for ***salt***, being ***sal*** and relating to the Greek ***hals***, and came up with ***salo***. Being paid in ***salt*** resulted in ***salaries*** while ***hals*** gave rise to ***halides*** or ***fish-breath***. A piece of ***land in the sea*** had begun as a ***terra in salo***, reducing to simply ***insalo***, something definitely ***insular*** and ***isolated***. The ***hydra***, one might recall, was a many-headed ***water snake***, or ***hydrus***, killed by Hercules. This Roman-Greek ***s-h*** relationship is also seen in ***solar*** and ***helium***, from ***sol*** and ***helios*** for the ***sun***, and, funnily enough, in ***silly*** and ***hilarious***.

There was a time when silver was thought to take on a life of its own and flow like water. Though we now refer to the material as ***mercury***, this ***watery silver*** or ***hygragyrum***, hence ***Hg***, was commonly called ***quicksilver***, not because it was fast but because it was ***lively***. ***Quick*** has the fundamental meaning of being ***alive*** and relates to ***vital*** and ***vivacious*** from the Latin ***vivas***, whose earlier form was ***qvivas***. The winged messenger ***Mercury*** was a fellow known to be rather lively, having wings on his feet and being the god of *travel*, *eloquence*, *cunning*, *theft* and ***commerce***, apparently handy attributes for ***merchants*** in the ***marketplace***, then and now.

I'm not sure if Mercury every got to ***Argentina*** but, if he had, his talents would have served him well. Named for ***argentum***, this land simply oozed with ***silver*** (***Ag***), though it didn't actually flow like water. The Greeks knew the metal as ***argyros***, simply meaning ***white*** or ***bright***, also seen in the ***white stone*** they called ***lithargyros***, now ***litharge***, or ***lead oxide***, all stemming back to ***rajata***, Sanskrit for ***white*** and ***shiny***. Should the preceding notions lead to an ***argument***, it would be quite appropriate as ***argue*** comes from ***arguere***, to ***make clear***, and links with the ***illumination*** associated with ***argentum***, as opposed to squabbling.

If one can't have silver, be happy with gold. The Roman ***gold*** was ***aurum***, hence ***Au***, the colour of ***dawn*** (***usas*** in Sanskrit), controlled by the goddess ***Ausosa*** (later altered to ***Aurora***) who associates with ***Eostre*** every ***Easter*** at the dawn of the new year (in the Northern Hemisphere). ***Gold*** itself links with ***chlorine*** and ***cholera*** by being ***geolu***, i.e. ***yellow*** (often greenish), also giving us ***gall***, ***glass*** and ***yolk***.

It is often said one should end with a good joke, but I'll settle for being a bit ***jovial***, or the original ***jovialis***, i.e. pertaining to ***Jove***, a grammatical from of Jupiter from ***dyaus*** via ***divam***. This requires that one's birth occurred under the ascendency of Jupiter, fating one to be ***joyous*** and ***jolly***, such being the astrological call signs of ***tin***. To the Romans, this was ***stannum***, hence ***Sn***, thought to link to the Celtic ***tain***. ***Stannum*** has also been ***stagnum***, also prepared by alchemists as an amalgam of silver and lead, and describing a pool of water with no outlet, leading to ***stagnation*** and ***stink***, while ***tain*** was a native tin bashed flat and polished as a mirror. In reflection, then, one might now be tempted to say that Jupiter has been reduced to the level of a little tin god?

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