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.

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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.

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In this issue ........

From the APCELL series Barnett describes a simple experiment in which the experimental results do not match the theoretical prediction of the kinetic salt effect. The experimental conditions have been designed to be noncompliant with specific limitations of the theoretical model. Although the results adhere to the general theoretical model, the data do not fit the theory; calculations reveal that one of the assumptions connected with the theory is not met. This experiment prompts students to consider the applicability of theory (and its limitations) when choosing or assessing an experimental protocol. As usual in the APCELL series, there is an educational analysis of the exercise, including consideration of theoretical and conceptual knowledge, scientific and practical skills, and generic skills.

Munk and George evaluate the effectiveness of a small group project involving a large first year chemistry course carried out at the University of Sydney. The groups, consisting of 5-6 students, engaged in two five-week projects to research, assemble and present a poster on a topic related to material covered in lectures. The assessment process involved peer- and self-assessment as well as instructor assessment. Somewhat surprisingly, many students did not want to take responsibility for their own assessment and preferred the instructor to be solely responsible for marking the posters.

Mamlok-Naaman, Navon, Carmeli and Hofstein present a case study in which teachers investigated their students’ understanding of electrical conductivity in the framework of an action research workshop. The teachers participated in a one-year professional development program aimed at promoting the teaching and learning of chemistry using action research methodology. The authors found that involving teachers in an intensive and comprehensive workshop dealing both with various aspects of teaching, and their investigation of their own work, provided them with an environment of support, collegiality, and the opportunity to collaborate with professional researchers and teachers who teach related subjects.

A study of student understanding of ions and ionisation energy is presented by Tan, Goh, Chia and Taber. They found that students from Singapore had similar alternative conceptions and explanatory principles of the factors influencing ionisation energy as did the A-level counterparts in the United Kingdom (U.K.). The results showed that students in Singapore applied the same octet rule framework and conservation of force thinking to explain the factors influencing ionisation energy as students did in the U.K. The authors believed that the way ionisation energy was taught and presented in textbooks could be the cause of students’ difficulties in understanding ionisation energy.

Lim describes the results of a survey to determine the ability of beginning university chemistry students to use ICT (information and communication technology) in their learning in 2002. The study found that there are minor deficiencies in the use of word processors, email attachments, the WWW; significant deficiencies were found in the use of spreadsheets, library databases, presentation software and computer conferencing, and major deficiencies in the use of relational databases.

Finally Mitchell presents another interesting discussion in his column The Word on Chemistry:

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Education in chemistry is becoming more popular!

In recent years there has been much said about the declining numbers of people studying chemistry at the undergraduate level. Or is it about the declining number of chemistry graduates? Are these the same thing? Certainly not! And the difference between these two forms of description is absolutely crucial.

Let’s accept that the number of students that we might define as ‘chemistry majors’ has dwindled and that, as a result, university chemistry departments have become smaller, have been merged with related disciplines, or even been disestablished. In summary, there are fewer people graduating now who might make the claim “I am a chemist”.

But is the number of people studying chemistry declining? I would wager not. Every biochemistry student must master chemistry to a reasonable level. As must many of the students whose major fields of study are environmental science, environmental engineering, chemical engineering, pharmacology, molecular biology, forensic science, soil science, nanotechnology, materials engineering, toxicology, .........., and a host of others. Surely we should recognize that these are all people who “do” chemistry. All of them depend on the knowledge and skills of chemistry to practise their profession.

Can it be argued that chemists have drawn a wall around ‘pure chemistry’ defined by the 1940s fields of inorganic chemistry, physical chemistry, organic chemistry and analytical chemistry? No I don’t argue that we chemists should look outside the wall. Rather, we should shift the wall. We should embrace the view that the people in the areas listed above (or, at least, many of them) are part of the chemistry community. If we take that view, then certainly we can declare that the number of undergraduates studying chemistry is escalating. Maybe we don’t have control of the escalating EFTSs, and the consequent income linked to student enrolments, and that is getting up our noses! It is my observation that the Divisions of the RACI indicate that the professional body opened its outlook much earlier than the universities have.

Through our narrow view of the discipline of chemistry, we have already lost the opportunity to embrace some of the emerging fields of science within Chemistry. But let’s hope that because of that, we don’t become even more inward looking. Perhaps the time has come for us to begin to reclaim our territory. Is it time to be more aggressive in convincing students of related disciplines of the need to study more chemistry. Is it time to assert more influence on the structure of the curricula of these related departments? At my institution, until very recently environmental engineering students took only one small unit of chemistry, and at the insistence of their home department, this did not include any organic chemistry. Can you believe that!? And we were wimpish enough to mount the unit because the ransom note said “...... or no chemistry at all!” or (shock horror!) ‘We will teach the chemistry to our own students”.

And on the subject of who should be teaching what, we seem to have been through a period of gnashing of teeth that other departments were getting more and more involved in teaching chemistry. If that is correct, surely it means that the other departments have thought that we weren’t ‘with it’ enough to supply what their students needed. Maybe, with some effort on our part, and some overdue recognition (assisted by our more assertive arguments) that a strong chemistry at the fundamental level is necessary, chemists might find themselves teaching to more and more and more of these students - within these other departments, and at their invitation.

And finally a word about the importance of a strong understanding of basic principles of chemistry. In my experience, this is a universal perception amongst not only chemists, but amongst the academic staff of the fields that I have listed above. And I agree totally. What I do not agree with is the logic that leads us to the conclusion that therefore chemistry should be taught by chemists in Chemistry departments. That is only a good thing if we (chemists) are capable of presenting the chemistry in relevant contexts. We have for too long bored many students out of their brains by believing that they should learn our principles in the trust that one day, a few years from now, they will see why it is useful. This is too much to ask of most students. [Should I say, of most people, including chemists trying to learn about other fields.] Perhaps the most important ingredient of an achieving student is motivation. And perhaps the most important ingredient to being motivated is knowing why it is important to know what you are being taught.

RBB
Reactions in non-ideal solution - The effect of ionic strength on the rate of reactions between ions in aqueous solution (the kinetic salt effect): An APCELL Experiment*

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Introduction
In chemistry, many experiments rely on a comparison of experimental results to theoretical models. For the most part, such comparisons are valid and reliable. In many cases, however, a theoretical expression may only be applicable under certain experimental conditions. For example, an ion selective electrode may only act in accordance with the Nernst Equation under a specified pH or temperature range. It is therefore important for students to be aware of potential limitations that may exist in order to reliably interpret experimental results using theoretical models.

In the teaching laboratory, exercises are normally pre-tested to ensure that experimental conditions yield results that consistently comply with theoretical expectations. Students may therefore become complacent when attempting to explain ‘errant’ results, automatically attributing them to ‘student error’ without considering alternative possibilities.

In this experiment, results are compared to the theoretical predictions of the Kinetic Salt Effect (which incorporates the Debye-Hückel Limiting Law). However, the experimental conditions have been designed to be non-compliant with specific limitations of the theoretical model. The experimental results adhere to general theoretical expectations, and the low degree of scatter in plotted data indicates that the experiment was carried out successfully, with minimal ‘student’ or ‘experimental’ error. Nonetheless, the results do not match the theoretical prediction of the Kinetic Salt Effect. Students are prompted to question the applicability of the theoretical model to their results. Their calculations reveal all solutions to have an ionic strength exceeding the specified limits of the Debye-Hückel theory. This determination triggers students to critically assess the applicability of theory to experiment when analysing data.

Further points of consideration that make this experiment an effective learning tool include:

- performing calculations fundamentally applicable to chemistry
- applying graphical analysis to experimental data
- the reaction studied is described by Activated Complex Theory (which is introduced in the Background Theory for the experiment).

Educational Template

1.1 Experiment Title
Reactions in Non-Ideal Solution - The Effect of Ionic Strength on the Rate of Reactions between Ions in Aqueous Solution (The Kinetic Salt Effect)

1.2 Description of the Experiment
In this experiment the Kinetic Salt Effect (the impact that increasing ionic strength has on the rate of a reaction in ionic solution) is explored. Students compare their findings to theoretical predictions. While being a simple experiment it offers several points of consideration for the student, making it an effective learning tool:

- Indirect measurements of chemical species. The reaction product (iodine) is difficult to measure directly, thus it is simpler and more accurate to monitor its production indirectly.
- The effect that altering a reaction mixture can have on the rate of a reaction. The reaction studied in the experiment is:

  \[ 2I^- + S_2O_8^{2-} \rightarrow I_2 + 2SO_4^{2-} \]

  The observed effect (reaction rate increases with increasing ionic strength) can be explained simply as the positive ion of the added electrolyte (Mg²⁺) draws the two negatively charged reactants closer, increasing the chance of a successful reaction. Students gain confidence when they are able to explain (perhaps with some prompting) an observation in a way that is clearly easy to understand. (Note that this can be expanded upon, however, if lecture material covers more extensive properties of ionic solutions including the Debye-Hückel theory of ionic solutions and the affect of ‘ionic atmosphere’ on ion reactivities.)

- While the equation(s) used are ‘simple’, they do require quite a bit of number crunching, which leads to...
satisfaction when completed successfully.

- Recognising a linear form of an equation and subsequent plotting of relevant data is always beneficial in Chemistry!
- Comparing experimental results with theoretical proposals triggers students to critically assess the applicability of theory to experiment. In this experiment, the theory is not obeyed (however limiting slopes may show that the theory is approached). Calculations show clearly that one assumption connected to the theory is not met (ionic strength exceeds the limit on which the theory is based). Students can therefore realise that failure to comply with theoretical expectations is not always simply due to ‘student error’, and it is therefore imperative that applicability of theory to each experimental protocol is also assessed.

Activated Complex Theory describes the reaction taking place, and is introduced in the Background Theory for the experiment.

1.3 Course Context and Students’ Required Knowledge and Skills

This experiment has a direct bearing on kinetics (with respect to reaction rates, catalytic effects etc.). It also deals with ideal and non-ideal solutions, ionic strength, activity coefficients, Debye-Hückel theory related to ion-ion reactions, and activated complex theory (ACT). Knowledge in these areas would naturally assist students, however the concepts are not too complicated and are covered in the laboratory notes.

Experimental skills required are the ability to use volumetric glassware – and simply being able to work a stopwatch.

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

While the origin of this experiment is unknown by the submitter, it has been adapted from past Physical Chemistry II laboratory course experiments implemented in the Department of Chemistry at The University of Adelaide.

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**Theoretical and Conceptual Knowledge**

- Backing up, clarifying or extending knowledge gained from lectures, tutorials, and self-study in the areas of:
  - a) Ideal / non-ideal solutions
  - b) The activity coefficient
  - c) Ionic Strength, Debye-Hückel limiting law, and Kinetic Salt Effect
  - d) Activated Complex Theory (ACT)
  - e) Effects on reaction rates (‘catalysis’)

- a-d) Students compare the results of their experiment to theoretical expectations based on a combination of these points, which are described in the Student Notes.
- e) Students see directly the catalytic effect the increase in ionic strength has on the reaction rate of their reaction mixtures.

**Scientific and Practical Skills**

- Volumetric techniques
  - Students make a series of solutions that require the use of volumetric glassware.
  - By observing their experimentally derived plot. While it should not be linear as theory predicts, it should still follow a smooth trend which would confirm that good volumetric technique was achieved.
## Generic Skills

| Ability to collate, correlate, display, analyse and report observations. Ability to present reports in appropriate formats. | Students record their experimental results, perform calculations on their results and construct relevant graphs. Students then construct 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). |
| Ability to consider limitations of theories when they are applied to practical applications. | Students discover that while their results follow the general expectations, they do not obey an expected trend based on theoretical predictions. ‘Experimental error’ cannot account for the deviation from theory as the results are neither erratically scattered nor biased. Students are therefore prompted to question the applicability of the theoretical prediction to their results: In this case, their calculations reveal all solutions to have an ionic strength $> 0.01$, yet the theory is based on an assumption of ionic strength $< 0.01$. | By recognising non-compliance to the theoretical prediction and explaining why this occurred. Students who do not accomplish this learning objective may attempt to ‘force’ a straight line through their data, ‘fudge’ a few data points to ensure linearity, or simply state that “the theory is obeyed as a straight line is observed… within experimental error anyway…” |
| Manipulation and presentation of data (plotting, spreadsheeting, etc) | Calculations of molarity followed by calculations of ionic strength for each reaction mixture is required. In our laboratory, students are able to perform these calculations how they wish. The calculations are complex enough, however, that a spreadsheet would be advantageous. Students are required to plot their graph(s) using computer software. | Correct manipulation of data can be checked by referring to ‘model answers’ provided to demonstrators. A predictable plot (slightly curved) is also indicative of successful data manipulation (as well as collection). |
| Problem solving: ability to apply problem solving in familiar and unfamiliar situations, and to display the capability of rigorous and independent thinking. | Students observe trends in their results that are expected (reaction rate increases with ionic strength), yet the results do not match the prediction of linearity given in the theory. These observations are easily explained after some thought by the student (with a little prompting by questions posed in the laboratory write-up). This encourages students to approach experimentation laterally, and to explore more than ‘experimental error’ when attempting to explain unexpected results. | Explanations of the observed results in the students written reports, as well as through oral communication/assessment with the demonstrator. |
| 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. The observations of predictable trends in their results, followed by the realisation that their results do not match theoretical predictions can also encourage teamwork as students work together to discover why. On occasion, students will question each other’s technique before questioning limitations that may be applicable to the theory. 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, 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 his/her written report after the laboratory session. 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. |
| Life-Long Learning: the capacity for and commitment to life-long learning. | In my opinion the ability to question before accepting is essential to life-long learning. This experiment encourages this approach, as the results the students obtain do not obey a theoretical relationship introduced in their Student Notes. On the other hand, the results do support the general theoretical expectations, and appear to be reliable as they follow a definite trend with very little scatter. Considering that both the theory and the experimentation are sound, students must therefore question what they have been told in order to understand the ‘discrepancy’ they see. | This will be indicated by students showing (through verbal communication as well as written reports) that they recognise that the experimental results do not match the theory yet both are sound. By successfully explaining the ‘discrepancy’ between experimental results and theory, students will have shown that they were able to question the theory and revisit it to explore the ‘fine print’ associated with it. |

### 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?**

S: Yes, I learned that the Debye-Hückel limiting law only applies for I<0.01, and that a reaction between 2 ions of the same charge (-ve in this case) can be catalysed by the presence of more ions of the opposite charge (+ve in this case) ie. by an increase in ionic strength.

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

S: It wasn’t too bad, but it took ages to equilibrate everything.

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

S: Easily; there is lots of time to think about the experiment while the solns are equilibrating.

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

S: There wasn’t enough room in the water bath to equilibrate all of the solutions at the same time, so you had to work together to organise space in the water bath and when you were going to do each mix. This worked OK.

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Small group learning in first year chemistry: Does it work?

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Abstract

In this study the effectiveness of small group project work as a teaching technique in a large first year chemistry class was evaluated. The aim of the project work was to enhance student motivation and learning in chemistry as well as to develop a problem-solving approach to chemistry, encourage group learning and develop communication skills. We found that most students responded positively to the new learning situation. A comparison of student attitudes to the project work at the time and one year after completing the unit suggested some benefits of the work were longer term in nature.

Introduction

Students often find chemistry concepts difficult, thus, effective learning situations are extremely important in enhancing student learning in chemistry. However, large class sizes in first year University chemistry courses have meant that implementing effective teaching strategies that are not resource intensive is a difficult problem. Lectures are easily the most cost-effective method of teaching first year chemistry, however, it is not necessarily the most effective learning situation for most students. Lectures may be inspirational and enjoyable and support good learning but this is very dependent on the skill of the lecturer. Studies have shown that chemistry students retain only a fraction of the material that they learn in lectures. Lectures may be an effective technique for transferring information, but, as described by Byers, “knowledge construction” is needed to achieve meaningful learning. Knowledge construction refers to the process by which students relate new material to what they already know. This is a time dependent process which different students approach in different ways. Here we describe ‘Group Work Projects’ which, when used in parallel to lectures, provide students with an opportunity to use the information transferred in lectures. Effective techniques in which teachers encourage “students to learn how to learn” outside of the lecture format are needed to enhance student learning and motivation.

Group learning methods have been shown to shift student learning from total recall to greater understanding of concepts. In a study conducted by Hamby Towns and colleagues, it was shown that small group work in teaching chemistry produced several positive outcomes, including learning, achievement and persistence. Dinan and Frydrychowski also found that small group (“team”) learning in organic chemistry supported student learning, and many students preferred this technique over the traditional lecture method. We chose to use small group tasks in a Chemistry 1 (Life Science) class to promote student learning and motivation.

Achievement motivation can be divided into two main areas: intrinsic motivation (student’s enthusiasm levels) and extrinsic motivation (ego enhancement, self-esteem). Several factors, such as novel teaching situations and student involvement, have been identified to influence student motivation levels. Group projects and interactive teaching techniques have been shown to assist in motivating student learning and to encourage students to adopt a deep approach to learning.

This Study

This study investigated students’ perception of the effectiveness of group work projects in parallel to lectures in learning chemistry. The group work projects were designed to provide students with an opportunity to apply the information learnt in lectures within the context of their degree, to encourage students to become an active part of their own learning and to aid development of skills such as literature searching, communication, presentation and critical evaluation. A questionnaire was used to gain feedback from students about the group work projects. The questionnaire was voluntary, anonymous and conducted by V.M. who was not involved in any other part of the teaching or assessment of the students. The questionnaire was paper based and conducted at the time when the students were engaged in the group work activity.

The class was Chemistry 1 (Life Science) which is a compulsory first year subject for all students enrolled in a Bachelor of Medical Science degree program at the University of Sydney. Two groups of students were surveyed – one at the time they were completing the projects (N = 210) and the other group were students in second year chemistry that had experienced the group work projects in the Chemistry 1 (Life Science) class the previous year (N = 66).

Group Work Projects

At the start of the group work projects, students were asked to divide themselves into groups of 5-6, resulting in approximately 40 groups. Each group was required to engage in two five-week projects to research, assemble and present a poster on a topic related to material covered in the lectures. In the first week each group chose a topic to work on from a list and were involved in a “brain-storming” session to discuss the information they needed, the issues involved and to delegate specific tasks to each group member. This was conducted during class time. A series of topics were available and some background information and a short paragraph highlighting possible
issues to kick-start discussion supported each topic. The project titles (examples given in Appendix 1) were selected so most had relevance to the chemistry being taught during the lectures. Groups were also allowed to choose their own topic in consultation with the course instructor (A.V.G.). While few groups elected this option for their first five week project, many more chose their own topic for their second project, which may indicate an increased level of confidence.

In the four weeks following the initial “brain-storming” session, students were asked to research their chosen topic and arrange the presentation of their poster, which was equivalent to approximately six A4 sheets. Each student was expected to allow one hour per week of his or her own time for the preparation of the poster. The posters were presented during class time in the fifth week.

The assessment process and criteria were explained and a summary of them provided at the start of the group work projects. The assessment process was designed to encourage critical analysis and involved both peer- and self-assessment by the students and assessment by the instructor of the posters. The relative weightings of peer-, self- and instructor-assessment were 1:1:2 with the mark for the poster contributing 10% to the semester mark of the student. The aim of the peer assessment was to encourage students to reflect on the quality and effectiveness of the material presented. In the light of this, self assessment becomes an important tool in recognizing improvements that can be made in one’s own presentation.

In the introduction to the group work projects, issues involved with group work were discussed and how group activities can develop generic skills. This was illustrated using Table 1.

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<tr>
<td>Group work / Peer interaction</td>
<td>“Brain-storming” session, group negotiations, ongoing discussions, presentation of poster.</td>
</tr>
<tr>
<td>Communication / Presentation</td>
<td>Preparation and presentation of poster, discussion of poster content.</td>
</tr>
<tr>
<td>Problem solving</td>
<td>Research of chosen topic, ongoing discussion, preparation of poster of a maximum size.</td>
</tr>
<tr>
<td>Research skills</td>
<td>Use of different information sources, selection of relevant material.</td>
</tr>
<tr>
<td>Time management</td>
<td>Preparation of the poster to a deadline.</td>
</tr>
<tr>
<td>Critical analysis</td>
<td>Peer- and self-assessment of posters.</td>
</tr>
</tbody>
</table>

**Table 1. Summary of generic skills and the specific activities that foster these skills associated with the group work projects.**

**Results**

**Classroom observation**

Observations of the class during the “brain-storming” session were positive, with most students approaching the session in an open-minded manner, with nearly all the students contributing to the group discussions. Students were enthusiastic about the task, and motivation levels appeared high. The groups were able to delegate responsibilities well.

In the poster presentation sessions, students were very enthusiastic to see the work of their peers, and to display their own work. While most students used this opportunity to read through many of the posters of their peers, a few saw this session as an opportunity to get an “early-mark”.

**Student Questionnaire**

Students were asked to respond to a questionnaire that was distributed to the class following the completion of the first poster session. A total of 46 questionnaires were returned representing a response rate of 22%. Second year chemistry students who participated in the group projects the previous year were also surveyed during a chemistry laboratory class. In this case 11 questionnaires were returned, representing a response rate of 17%. The questionnaires required a short answer response and were initially analysed by dividing them into positive and negative responses. The proportion of positive responses received for each question from first and second year students is represented graphically in Figure 1.

![Figure 1. Positive responses to survey questions by First and Second year students.](image)

Question one (How did the poster sessions support your learning in chemistry?) examined the students’ perceptions of the effectiveness of the group learning project in supporting their learning in chemistry. All of the second year students surveyed felt that the group projects had supported their learning in first year chemistry, whereas only 63% of the first year students responded positively to question one. Many of the positive responses stated that the “project allowed applications of chemistry to be explored”, the “information (that they) acquired in the project was retained” and that the project helped the students “understand concepts covered in lectures”. However, some students felt that the project was of minimal help in supporting their understanding of the material covered in the lectures and they felt that it did not relate directly to the end of semester examination.

Question two (What additional skills did you acquire by participating in the poster session?) looked at the additional skills that students felt they developed during the group projects, with 91% of the second year students and 57% of first year students responding positively. The
skills that the students identified as being developed in the project were group learning, teamwork, communication, research/internet skills, presentation skills and organisational skills.

Students were asked about their feelings on the peer assessment component of this task in question three (Did grading classmates’ posters influence you approach to the session?), with only 36% of second year students and 34% of first year students surveyed responding positively. Most students did not enjoy assessing the projects of their peers, and they felt that the process was somewhat subjective, even though they were provided with detailed assessment criteria. Some felt that not all their peers took the process seriously and were likely to mark their friends more highly than peers they did not know. The general feeling of the responses was that the students preferred the instructor to be solely responsible for marking the posters.

Question four (What did you learn from the posters your classmates produced?) probed the students’ perception of the effectiveness of interactive learning in this task, with 73% of second year students and 51% of first year students responding positively to the question. Students identified that reviewing the posters of peers enabled them to gain an insight into a variety of topics and to discover different techniques to present material. However, time pressures prevented several students from reviewing many posters.

Question five asked the students to provide constructive feedback on the group work project. This is part of an ongoing action research plan to improve the group work projects for future years. Students felt changes in the marking scheme were necessary, with the instructor entirely in charge of the assessment. The students also felt that there was a need for smaller groups and better guidelines of what format was expected for the posters. They suggested viewing posters from the previous year would help.

Additional questions were directed to the second year chemistry students to evaluate the longer-term benefits of the group work projects. The students felt that the change from the lecture theatre to a more hands-on approach was enjoyable, and most students recalled the material that they (and some of their peers) covered in the task. Although none of the students felt that the project directly influenced their decision to take second year chemistry, they recognised it was a combination of the posters, lectures, tutorials and laboratory sessions that influenced their decision.

Exam Performance
It is difficult to gauge the effect that the group work projects have on the chemistry knowledge of the students, as there are many variables involved. However, in the first year that the projects were introduced, there were two lecture streams of the Chemistry 1 (Life Science) class (A and B). Students of stream A were engaged in a compulsory one year chemistry course as part of a Bachelor of Dentistry degree (N = 48) while those of stream B were engaged in a compulsory one year chemistry course as part of a Bachelor of Medical Science degree (N = 188). There was no movement of students between streams and no students joining or leaving the streams between semester 1 and semester 2. The two lecture streams were taught the same chemistry syllabus by the same instructors in both first and second semester and the students sat identical examinations. The average mark on the examination at the end of first semester differed by 3% with stream B performing better than stream A. In second semester only stream B did the group work projects. In the second semester examination the average mark of students in stream B had risen to 10% greater than that of stream A.

Discussion
Feedback from the group work projects was positive overall with students appreciating the chance to have input into the material that they were learning. A number of responses given by the first year chemistry students differed from those given by the second year students. This may have arisen due to two factors: the second year students are more “mature” and reflect informatively on the group work projects or that the students that are motivated after first year choose to study second year chemistry.

The benefits of group-based learning are widely recognized; however, there is still much that we need to learn to utilise this technique fully.13 It may be that some students are uncomfortable with group work because of factors such as social anxiety14 and consequently these students may benefit less than their peers from the process. More problematic, however, is group assessment since individuals may not contribute equally to a group assignment. This inherent unfairness of group assessment contributes significantly to student’s negative perception of group work, again diminishing the benefits of this type of learning. To address this, peer assessment may be used to determine individual effort, providing a basis for awarding individual marks.15

The purpose of the peer assessment was to develop critical evaluation skills among the students and enable them to improve their presentation skills by viewing a range of poster layouts. However, many of the students surveyed did not want to take responsibility for their own assessment. Although the students were provided with the assessment criteria at the start of the group work projects, it was felt that the peer assessment process was too subjective and many students expressed the view that they preferred the posters to be marked solely by the instructor. Students were given the opportunity to rank the involvement of each member of their group, but some students felt this was difficult to do. The marks awarded for the posters by peers (while maintaining confidentiality of the peer marker) and instructor were displayed to the students after the first group work project. The congruence
between the marks appeared to increase student confidence in the peer assessment used.

Other aspects of the small group tasks that students felt needed to change were group sizes and the introduction of oral presentations. Many students felt that the group size of approximately 5 people was too big for the students to effectively work together. Students had difficulty finding convenient times and places to collaborate on their presentations and found that the workload was not equally distributed. The introduction of oral presentations may help the students. However, with a class-size of over 200 this is probably not practical given the time constraints, as it would be difficult to assess and coordinate.

Overall, it was felt that this teaching technique does promote long-term motivation and learning. The second year students reflected extremely positively on the projects, and also remembered a large amount of the material that they had learnt from both their own research and the work of their peers. This suggested the benefits of the group work projects could be longer term in nature.

Conclusions

The teaching technique implemented in the Chemistry 1 (Life Science) class was aimed to enhance student motivation and learning. There were four main conclusions to the study. Firstly, the students found the material covered in the group work projects interesting, and found understanding some chemical concepts covered in lectures less difficult. Secondly, student motivation levels in learning chemistry did increase after participating in the group work sessions. Thirdly, the students did not find peer assessment a positive aspect of the group work project. Finally, the second year students reflected positively on their participation in the group work project, with most students able to recall the material that they had learnt.

From the feedback received, both the first and second year students surveyed felt that the small group projects did positively influence their motivation levels and student learning. The information received from the students regarding the small group projects will be used in the second phase of this action research project to further improve the directed learning tasks.

References


Appendix 1 - Group Work Projects (First round)

A Why recycle aluminium cans?
B How else could we display the periodic table?
C What differences are there between oils and fats?
D Are vehicle emissions bad news?
E Should fluoride be added to drinking water?
F There are acidic, basic and neutral amino acids – how is polarity linked with protein structure?
G Acid stomach, basic intestine, neutral blood – how and why the differences?
H What characteristics should artificial blood have?
I Any other topic you like by negotiation with Dr Adrian George!

An invitation

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

- Short papers on chemistry topics or concepts, from an educational perspective
- Reflective papers teaching and learning chemistry - general or specific
- Letters to the editor
- Announcements
- Forthcoming events
- Books to review
- News about people or places
Teachers research their students’ understanding of electrical conductivity

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Abstract
In this paper, we present a case study in which teachers investigated their students’ misconceptions in learning about the electrical conductivity of metals and ionic materials in the framework of an Action Research workshop. In Action Research, teachers research their own practice of teaching. More specifically, they undertake tasks that they have not undertaken before. We found that involving teachers in an intensive and comprehensive workshop dealing both with various aspects of teaching, and their investigation of their own work, provide them with an environment of support, collegiality, and the opportunity to collaborate with professional researchers and teachers who teach related subjects.

Introduction
Ten high-school chemistry teachers and two staff members from the Science Teaching Department at the Weizmann Institute of Science in Israel, who served as coordinators, participated in a one-year professional development program aimed at promoting the teaching and learning of chemistry using Action Research methodology. In Action Research, teachers research their own practice of teaching. More specifically, they undertake tasks that they have not undertaken before. The program described here involved monthly meetings throughout the school year at the Science Teaching Department of the Weizmann Institute of Science, Rehovot, Israel.

The objectives of the study were as follows:
1. To use Action Research as a tool for the professional development of the chemistry teachers.
2. To encourage the creation of a professional community of chemistry teachers.
3. To establish a leading-teachers’ team who will perform Action Research with teachers.

Here we present a case study in which teachers investigated their students’ misconceptions in learning about the electrical conductivity of metals and ionic materials, in the framework of an Action Research workshop, using students’ interviews and an achievement test as their research tools.

Theoretical framework
Action Research is an inquiry into teachers’ work and their students’ learning in the classroom (Feldman & Minstrel, 2000). According to Feldman (1996), the primary goal of Action Research is not to generate new knowledge, whether more local or universal but rather, to improve and change classroom practices. The process of Action Research can be described as a cycle of planning, implementation, observation, and reflection. Implementing changes and improving classroom practices is an iterative process (Kemmis & McTaggart, 1988; O’Hanlon, 1996; Zuber-Skerritt, 1996). Each cycle of Action Research is repeated and all cycles form a spiral. These cycles allow teachers and researchers to evaluate classroom practices for ongoing improvement (Towns, Kreke, & Fields, 2000).

The way Action Research is done (cyclical) is one of the main differences between Action Research and more conventional research (Wadsworth, 1998). Lewis and Munn (1987) indicated three main reasons for conducting teacher-based research: (1) to try to determine what is actually going on, (2) to monitor and thereby formatively influence the direction of new developments, and (3) to evaluate what is already taking place.

According to Feldman and Minstrel (2000), the main reason why Action Research should become an integral part of implementing the curriculum is that it reduces the time lag between the generation of new knowledge and its application in the classroom. Loucks-Horsley, Hewson, Love and Stiles (1998) claim that the strength of Action Research as a professional development strategy is that teachers either define the research questions or contribute to defining them in a meaningful way, and are actively involved in the teaching process (Parke & Coble, 1997).

The use of action research as a strategy for professional development is based on the following assumptions (Loucks-Horsley et al., 1998, p.97):

- Teachers are intelligent, inquiring individuals with important expertise and experiences that are central to the improvement of education practice.
- By contributing to or formulating their own questions and by collecting data to answer these questions, teachers grow professionally.
- Teachers are motivated to use more effective practices when they are continuously investigating the results of their action in the classroom.

In their book Designing Professional Development for Teachers of Science and Mathematics, Loucks-Horsley et al. (1998) wrote that:

Action Research has evolved in the education community into an ongoing process of systematic study in which teachers examine their own teaching and students’ learning through descriptive reporting, purposeful conversation, collegial sharing and critical reflection for the purpose of improving classroom practice.(p.95)
In order for action research to be an effective means for helping teachers to reflect on their practice, we must provide them with opportunities to engage in life-long professional development. These opportunities should provide them with an environment of support, collegiality, and collaboration with professional researchers and other teachers who teach the same or related subjects, an environment that encourages reflection on their classroom practice and the results of their research efforts. According to Holly (1991), collaboration is now seen as a major form of professional development. Indeed, this collaborative inquiry should be conducted by professionals acting as reflective practitioners (Schon, 1983). When teachers reflect critically on their experiences, they critically examine them and improve their ability to teach and understand their students’ learning difficulties (Obaya, 2003).

Typically, teachers who are inexperienced in Action Research need support and training regarding its methodology, procedures, and activities. This includes designing tools, collecting data, analyzing and interpreting the results, and finally, applying the findings in the science classroom. Engaging in professional development provides the teachers with an opportunity to share the results of their classroom research and related pedagogical activities with their fellow teachers, who will later provide them with feedback and other ideas.

In recent years, Action Research has been widely used as a tool for the professional development of teachers in all stages of their career, including the pre-service preparation of teachers. The following are a few examples from the literature about programs for the professional development of teachers regarding Action Research, for prospective teachers. Korthagen (1985) described how a Dutch teachers’ education school developed a program on how to prepare future teachers to reflect on their experiences as a means of directing their own growth in the profession. Gipe and Richards (1992) conducted a study in which they examined the relationship between future teachers’ reflections and growth in their teaching abilities in any early placement field. The analysis of data that was collected over one semester from various journals and multiple observations indicated that teacher preparation programs should foster reflective thinking as an important aspect of their teaching abilities. Gore and Zeichner (1991) stressed the importance of Action Research in the framework of different conceptions of reflective teaching, regarding the social view of reflection that underlies the University of Wisconsin-Madison elementary teacher education program. The study was conducted by one supervisor and eighteen student teachers from 1988 – 89 and analyzed for evidence of the favored view of reflective thinking.

In this paper we present an Action Research study of two chemistry teachers who investigated their students’ understanding of electrical conductivity, which was conducted under the sponsorship of an Action Research workshop. In the next section we describe the Action Research workshop and the specific case study mentioned.

The Action Research workshop

As mentioned before, ten high-school chemistry teachers and two staff members from the Science Teaching Department, who served as coordinators, participated in a one-year professional development program aimed at enhancing the teaching and learning of chemistry using Action Research methodology. The program involved ten monthly meetings throughout the year, conducted at the Science Teaching Department of the Weizmann Institute of Science.

The syllabus of the workshop was planned based on the following assumptions: The participants were experienced chemistry teachers and had background in both chemistry content and pedagogy. Nevertheless, they lacked experience doing research and were not acquainted with the qualitative research paradigm in general and the Action Research in particular.

The workshop consisted of the following issues and topics:

- Action Research principles
- The qualitative research approach
- Methodology: rationale for choosing the subject for research; defining a good research question for Action Research; research tools and data collection (questionnaires, interview, and observation); data analysis.
- Reflection at each of the stages
- Written reports.

During the first four meetings, the workshop coordinators presented the theoretical framework and issues; the following meetings were devoted to discussions with the participants on the various stages of their classroom-based Action Research: (1) identifying the general problem and their own research question, (2) planning the research including the development of the research tools, (3) data collecting and analyzing, (4) implementing, (5) data collecting and analyzing, and (6) evaluating and reflecting.

The various stages are presented in Figure 1.
After each meeting of the research group, the participants met with their colleagues at school, and shared with them the topics and subjects discussed at the workshop. In this way, they involved the whole team of chemistry teachers at their school in the “Action Research” process. During the meetings, the participants reported on their work, discussed the difficulties that had arisen throughout their teamwork, and received comments, clarification, and support from the other participants and the workshop coordinators. The participants were advised to choose research questions that were relevant to their work in school and in the classroom. The questions had to be related to the students’ achievements and/or behavior. Some examples of the “Action Research” issues that were chosen by the workshop participants are presented below:

- What misconceptions do students who study the electrical conductivity of metals and ionic materials have and how can we cope with them?
- What will be more effective in teaching the topic “Proteins” – using graphic demonstrations or presenting tables?
- Will innovative teaching strategies motivate and improve 10th grade chemistry students’ attitudes toward chemistry studies?
- Can we change students’ attitudes toward science by integrating relevant, everyday issues into their science curriculum?

We will now describe in detail a case study in which two teachers investigated their students’ misconceptions in learning the concept of the electrical conductivity of metals and ionic materials.

The case study

Background

For the purpose of this paper, it was decided to describe the case study of Sarah and Debra, two experienced chemistry teachers from a regional high school in a small town in the center of Israel, with a 10th grade class of students who finished junior high-school studies at the same school. Sarah and Debra had 22 and 12 years, respectively, of high-school chemistry teaching experience. The team of chemistry teachers in their school consisted of 5 teachers, with Sarah serving as the chemistry teachers’ coordinator. Sarah participated in leadership courses, as well as in long-term in-service professional development workshops. She presently serves as a regional high school chemistry consultant and participates in a few high-level curricular committees, regarding high-school chemistry studies. We decided to focus on their issue, “What misconceptions do students who study the electrical conductivity of metals and ionic materials have and how can we cope with them?” which dealt with students’ misconceptions in learning about these subjects. We made this decision, since the data that they had collected and their findings regarding learning about electrical conductivity stressed the effectiveness of the Action Research approach in helping teachers to cope with the cognitive aspects of learning. Both Sarah and Debra were concerned for a long time about their students’ difficulties in understanding electrical conductivity and their students’ misconceptions regarding metals and ionic solutions.

Electrical conductivity is a problematic concept; there are studies in the literature dealing with misconceptions about electrical conductivity and electrochemistry. Coll and Taylor (2001) found 20 alternative conceptions of chemical bonding by examining senior secondary and tertiary level chemistry students. During discussions on the electrical conductivity of copper, they found that students held alternative conceptions about electrical conductivity. Garnett and Treagust (1992) used semi-structured interviews to investigate students’ understanding of electrochemistry. Three misconceptions were identified and incorporated, along with five previously reported, into an alternative framework about electric current involving drifting electrons. Sanger and Greenbowe (1997) examined students’ misconceptions and proposed the mechanism of the current flow in electrolytes. They reported some misconceptions and identified several new ones. In addition, they discussed probable sources of misconceptions and methods for preventing them. Huddle, White, and Rogers (2000) described a concrete teaching model designed to eliminate students’ misconceptions about current flow when they study electrochemistry. The model uses a semi-permeable membrane rather than a salt bridge to complete the circuit and demonstrates the maintenance of cell neutrality.

The authors concluded that the use of the model led to an improvement in the students’ understanding at the high school and university levels. Ozkaya (2002) referred to a previous study of prospective teachers, which found that students from different countries and different levels hold common misconceptions about electrochemistry, indicating that the concepts were poorly presented to them. Niaz (2002) reported on a research study that constructed a teaching strategy that may facilitate conceptual change in freshman students’ understanding of electrochemistry. In the study it was found that providing students with the correct response along with alternative responses (teaching experiments) creates a conflicting situation that is conductive toward an equilibration of their cognitive structures. It was concluded that the ‘teaching experiments’ facilitated students’ understanding of electrochemistry.

Sarah and Debra, the two teachers in the Action Research workshop, tried to determine the reasons for the students’ lack of understanding of electrical conductivity. They realized, that while planning their instruction, they had assumed that their students had previous knowledge about the subject, because those issues are taught in junior high school (7th–9th grade). The junior high-school science curriculum includes a course dealing with electrical conductivity, namely “electricity and chemistry”. It consists of basic concepts of electricity and chemistry, e.g., the electrical flow, the electrical charge, the electrical charges in the material, and the conductivity in ionic solution, metals, and the atoms.

Sarah and Debra were concerned about the basic knowledge of their students, specifically their
understanding of electrical conductivity and their knowledge from their previous studies. Thus, they decided to make a change in the teaching procedure and consequently in their students’ knowledge of electrical conductivity. They decided to create some tools to investigate their previous knowledge, and consequently changed their teaching strategies according to their findings.

**The research question**
The research question selected for investigation was as follows:

“What are the misconceptions of students who study the electrical conductivity of metals and ionic materials, and how can teachers cope with them?”

**Research Tools**
The tools consisted of interviews and an achievement test following the completion of the teaching procedure.

1. **Interviews:**
The interviews were half-structured and consisted of cognitive questions, aimed at determining what the students understood, using a model of an electrical circle. The interviewer was allowed to add or omit questions according to the interviewee’s answers. The students were asked about two circles consisting of a lamp and electrodes. At the beginning of the experiment, they put a metal between the electrodes and afterwards they poured an ionic solution. Each interview was recorded. Figure 2 illustrates the circle.

![Figure 2: An electrical circle](image)

2. **An achievement test**
In addition to the repeated interviews, the impact of the new strategies on students’ knowledge was evaluated using an achievement test in class. The test consisted of three different parts (for more details, see Appendix 1).

**The stages of the Action Research**
The Action Research study should be conducted as a spiral process (Towns, Kreke, & Fields, 2000). As illustrated in Figure 1, the research was conducted in various stages. The first two stages, which dealt with the identification of the problem, the research question, and with the planning stage, were described previously. The description of stages 3, 4, 5, and 6 follows.

**Stage 3. Data collecting and analyzing**

**Interviews**
The teachers began the study by interviewing students (three low achievers, three intermediate achievers, and three high achievers). After completion of the learning process, they conducted the same interviews in order to evaluate the students’ knowledge.

The following is a transcript of an interview conducted with a 10th grade medium achiever student. The interview consists of two parts:

**The interview**

**Part 1: The electrical circle is closed with a metal.**
Teacher: {the teacher puts all the parts of the circle on the table} we are going to start with a circle. Do you recognize all the parts?
Student: Yes.
Teacher: {the teacher connects all the parts of the circle as illustrated in the diagram} I am closing the electrical circle with a copper strip. Can you describe the molecular structure of the copper?
Student: A collection of similar atoms. I know the properties of metals in general but not specifically those of copper.
Teacher: Can you draw the copper particles as they appear in the metal strip?
{The student draws...}

Teacher: The copper has a role in the circle and now we see that the lamp illuminates. Why does the lamp illuminate?
Student: The circle was open and when you connected the copper strip to the other parts, it became a closed circle, since the strip can conduct electrons, which pass through it.
Teacher: Where do the electrons come from?
Student: From the battery.
Teacher: Do you think that the battery stores the electrons?
Student: Yes! Protons and electrons as well.
Teacher: What would you see if you could be inside the circle and be a part of the flow of the electrons?
Student: I would pass through the whole circle, and could see how an electron flows with other electrons.
Teacher: What happens to the electron when it reaches the lamp?
Student: It passes through the lamp.
Teacher: What happens to it when it reaches the battery?
Student: It continues through the circle and does not stop in the battery.
Teacher: Were there any electrons in the copper before I closed the circle?
Student: There were electrons in it because it is a metal. It has its own electrons, and not those of the battery.
Teacher: If I were a magician and I could paint the electrons of the copper in red, where could I find them?
Student: I do not know, I think that they stay in the metal itself.
**Part II: The circle is closed with an ionic solution.**

Teacher: This circle of electricity consists of the same components as the first circle: a battery, a lamp, and two electrodes. Instead of the copper strip, we closed the circle with an ionic solution, copper chloride (CuCl₂). Can you draw the particles of the solution?

{The student draws...}

Teacher: Do you think that there is something else in the glass?

Student: I do not think so. There are electrons of copper chloride.

Teacher: What happens when I close the circle?

Student: I see that the lamp is illuminating. It is a sign that the circle is closed and that it conducts electricity as in the circle with the copper stripe.

Teacher: Did you observe anything else?

Student: I can see that there is something in the area of the electrodes. I think that it is melting. There are air bubbles from it. I know what it is!! It is oxygen.

Teacher: On the second electrode there is something, can you see it?

Student: The color changed.

Teacher: If you could “accompany” the electrons that come out of the battery as you mentioned, what would happen to them?

Student: They would pass through the tire, reach the lamp, continue through the electrode to the solution, pass through the solution and continue with the tire to the battery.

Teacher: Do you think that before I closed the circle, there were changes in the solution that can transfer the flow?

Student: Yes.

Teacher: What are those changes?

Student: Electrons, protons, copper, and chlorine (the components of copper chloride).

An analysis of this interview revealed misconceptions that were typical of many students who were involved in this study. More specifically, students think that:

- The particles that are charge carriers are electrical particles, atoms, and protons.
- There is a flow of energy.
- The battery is the source of the electrons.

The teachers (who participated in the workshop) concluded that students have difficulties with the following:

1. Understanding the accumulation of atoms concept.
2. The integration of the macroscopic and microscopic worlds.
3. The fact that the flow carriers in the ionic solution are not electrons.
4. The fact that each compound that consists of a metal may conduct electricity in certain circumstances

**Stage 4. Implementing: teaching a topic while focusing on a variety of strategies**

Based on the results of the interviews, the teachers decided to include a new pedagogical approach to teach this topic. The experience gained in the professional development courses for chemistry teachers helped them understand the importance of using different and varied teaching approaches during the teaching process (Harrison & Treagust, 2000; Harrison & Treagust, 1996; Hoffman & Krajcik, 1999). Based on that, they decided to teach using:

- Models for demonstrating the particulate nature of matter. The teachers asked the students to draw models during their classes, for example, copper ions in the solution, the structure of water, components of an ionic solution in a glass vessel, the metal atom with the cloud of electrons, the solid structure of a metal, the flow of electrons in the metal strip, and the conductivity of an ionic solution.

- Videos and slides, such as structured observations of the video “the metals”. This video is one in a series of movies called “the chemistry world”. It shows different metals and compares their properties. The students can observe visual examples of the different metals and the description of the conductivity of the metals through detailed animations and clear models.

- Educational computer programs of the structure, bonding and properties of compounds, developed by the Chemistry Group, Science Teaching Department, the Weizmann Institute of Science, Rehovot, Israel.(http://stwww.weizmann.ac.il/g-chem/htm)

- This program includes a virtual laboratory that enables the students to get practice in planning and performing experiments. There are also special components that deal with ionic and molecular compounds, games, mini projects, and the electronic representation of formulations. The macroscopic phenomenon can be examined from the microscopic point of view.

- Computer animations, e.g., an animation is illustrated in Figure 3.
Stage 5. Data collecting and analyzing (after completion of the focused teaching)

I. Interviews

After the teachers finished the focused teaching process, they again interviewed the same students and administered an achievement test to the whole class.

An example of an interview including the same two parts of the electric circles described in the first interview follows.

Part I: The electrical circle is closed with a metal.

Teacher: We have here a copper strip. Can you describe the structure of the copper?
Student: There are positive nuclei and a cloud of electrons that flow inside the metal.
Teacher: Can you describe the particles in the strip?
Student: Electrons, protons, and neutrons.
Teacher: What are parts of the nucleus from the ones you mentioned?
Student: Protons and neutrons.
Teacher: Do you think that all the electrons of the metal take part in the cloud of electrons?
Student: No, there are more electrons that do not take part in the cloud of electrons.
We learned that not all the electrons participate in the cloud of electrons.
Teacher: Why do you think that there is a difference between those that take part and those that do not take part in the cloud of electrons?
Student: When we connect the copper to the circle there are electrons that flow in the circle and others that do not.
Teacher: The circle is built from the battery and the copper strip. If I could label the electrons of the copper, would they move in the circle?
Student: Yes, they will flow.
Teacher: Do the electrons have any special behavior?
Student: Yes, they move in one direction.
Teacher: Try to draw the microscopic structure of the copper:

![Microscopic structure of copper](image)

Teacher: What is the role of the battery?
Student: The battery directs the electrons.

Part II: The circle is closed by an ionic solution.

Teacher: Can you please draw a model of the particles in the ionic solution of copper chloride

![Ionic solution of copper chloride](image)

The ions are not together and there is an attraction between them.
Teacher: If there is an attraction between them, why are they not connected to each other?
Student: Because of the water, they separate between the plus and the minus poles, and there is no precipitate.

Teacher: If we connect the solution by electrodes to a voltage supplier, will there be a flow?
Student: Yes.
Teacher: The electrodes do not touch each other. How does the current flow?
Student: The positive ions move to the negative electrode and the negative ions move to the positive electrode.
Teacher: In what direction do the positive ions move?
Student: To the copper electrode.

II. Achievement Test

The test consisted of three different parts. In the first part it was not enough to answer if the statement was true or false, the students had to explain their answers. In this way the teachers could check the students’ understanding of electrical conductivity. The last specific question dealing with the materials that the students were asked about in the interviews was very important and really reflected how well the subject was taught. The distribution of the students’ grades was normal. The mean grade was 80%.

Stage 6. Evaluating and reflecting

Based on test results and an analysis of the repeated interviews, the teachers reported that more students were able to distinguish between the electrical conductivity of metals and the electrical conductivity of ionic solutions, the pulse carriers in the different conductors, and the characteristics of copper as a metal, and copper chloride as an ionic solution. Their ability to use models during class time activities and in their answers in tests and other assignments increased, and their explanations about the relationship between the macroscopic and microscopic world improved, as well as their knowledge about the particulate nature of matter.

However, both Sarah and Debra mentioned that there were still a small number of students who were “stuck” with the notion that electrons are the only pulse carriers. Thus, Sarah, the senior teacher, claimed that she should better investigate her students’ knowledge and understanding in each of the topics that she taught, although it would make a change in her lesson plans and in the pace of teaching a certain subject.

Concluding remarks

The results of our study showed that Sarah and Debra experienced a new process for professional development. They got new insights regarding their teaching and were able to improve and promote their classroom instruction. The topics discussed at the workshop enabled them to realize that a reflective study has its own value and is indeed beneficial to their work. It strengthened their teamwork at school and encouraged collaboration between themselves and their colleagues. They supported each other in their work at school in general, as well as regarding their Action Research study. They claimed that the fact that they had presented their studies in the annual conference of chemistry teachers in Israel strengthened their self image as professionals. Moreover, both Sarah and Debra were promoted as leading teachers in their school. Sarah conducted a one-year project of E-learning and became an expert in this domain, and Debra was in charge of a biotechnological project in her school.
As Joyce and Showers (1983) suggested, teachers are interested in improving and enriching their teaching methods, and Action Research in particular has been a new experience for those teachers who participated in the workshop. The teachers were enthusiastic, but still inexperienced in conducting a reflective study. Usually they are involved in positivistic studies (in which there are experimental groups and control groups) and therefore usually do not take part in qualitative reflective research. Thus, they needed adequate instructions and guidelines regarding the research tools and the data analysis. It was not easy for them to adopt the paradigm of qualitative research. Thus, the workshop coordinators had to devote a significant part of the time to discuss the tools of the research and the data analysis.

The workshop provided an environment of support, collegiality, and collaboration with professional researchers and other teachers who teach the same or related subjects, in a milieu that encourages teachers to reflect on their classroom practice and on the results of their research efforts. The lectures that those teachers attended at the workshop enabled them to undergo a conceptual change and to realize that a reflective study has its own value and is indeed beneficial to their work (Elkis & Ralle, 2002).

All the teachers were very enthusiastic about the fruitful discussions during the workshop, and claimed that the workshop contributed a lot to their work and to their ability to find solutions to their problems. Moreover, they were more satisfied with their teaching, and had closer contact with academic institutions on a professional basis. In addition, they became more concerned about improving their practice and learned how to share their ideas and experiences with their colleagues.

Acknowledgement

The authors would like to thank the teachers who took part in the workshop for their collaboration and cooperation.

References


Appendix 1:  
An achievement test
A. Statements, for which each answer was “true” or “false”. In addition, the students had to explain their answers.

a. Ionic material does not conduct in the solid phase, since in this phase there are no ions. True / False

b. Aluminum chloride conducts in the solid phase, since it does not consist of ions. True / False

c. Copper chloride conducts in the solid phase due to the flow of the electrons. True / False

d. Each solution conducts electricity. True / False

e. The melting point of an ionic solution depends on the charge of the electrons. True / False

B. Open-ended questions
I. Write the empirical formula of the ionic materials written below:
   a. Potassium Iodide
   b. Magnesium Phosphate
   c. Barium Oxide
   d. Calcium Sulfate
   e. Calcium Hydroxide
   f. Sodium Carbonate

II. Complete and balance the following processes:
   1. KI (s) → H₂O(l)
   2. ZnSO₄(s) → H₂O(l)
   3. CuBr₂(s) → H₂O(l)
   4. Na₃PO₄(s) → H₂O(l)
   5. K₂CO₃(s) → H₂O(l)

III. “Copper and copper chloride:
   1. Are they solid at room temperature?
   2. Can they conduct electricity at room temperature?” Explain!

Continuation from page 8: An APCELL Experiment

3.6 Did you have the opportunity to take responsibility for your own learning, and to be active as learners?
S: To get a decent mark in any prac you have to understand what it’s about; asking questions, rereading the prac. notes and reading through the relevant sections of the textbook are essential in doing this. The opportunity to do all of these things was certainly there; the demonstrators were especially helpful.

3.7 Does this experiment provide for the possibility of a range of student abilities and interests? If so, how?
S: The experiment was specific; it taught you about the Debye-Hückel limiting law and a bit of qualitative activated complex theory. The calculations were reasonably challenging (but far from impossible) and for an extra challenge, you could derive the equations given in the prac. manual*.

(*Note, the Student Notes have since been modified to incorporate the majority of relevant derivations.)

3.8 Did the laboratory notes, demonstrators’ guidance and any other resources help you in learning from this experiment? If so, how?
S: The prac notes were adequate for the preparation and write-up of the experiment and the demonstrators were especially helpful.

3.9 Are there any other features of this experiment that made it a particularly good or bad learning experience for you?
S: I certainly remembered that the Debye-Hückel limiting law doesn’t apply when I>0.01, so it was useful in that respect.

3.10 What improvements could be made to this experiment?
S: I like the idea of including Assessment Criteria and intended learning outcomes in the prac. notes – it means you have some idea of what you have to look out for as the experiment proceeds*.

(*Note, this pertains to a previous version of the Student Notes, where this information was not included - at that time, this information was only beginning to be incorporated into some experiments. It has subsequently been included in the Student Notes for this experiment.)

3.11 Any Other Comments
none
Ions and ionisation energy

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Abstract
Previous research (Taber, 1999, 2000a) has shown that A-level students in the United Kingdom had difficulty understanding the concepts involved in ionisation energy. The purpose of this study, which involved the use of interviews and written instruments, was to determine if Grades 11 and 12 students (16 to 19 years old) in Singapore had similar alternative conceptions and explanatory principles of the factors influencing ionisation energy as their A-level counterparts in the United Kingdom (U.K.), as well as to explore students’ conceptions of the trend of ionisation energy across different elements in the Periodic Table. The results showed that many students in Singapore applied the same octet rule framework and conservation of force thinking to explain the factors influencing ionisation energy as students in the U.K. In addition, the students resorted to relation-based reasoning to explain the trend of ionisation energy across period 3 elements. The authors believed that the way ionisation energy was taught and presented in textbooks could be the cause of students’ difficulties in understanding ionisation energy. Teachers and textbooks need to focus explicitly on the effects of nuclear charge, the distance of the electron from the nucleus, the repulsion/screening effect of the other electrons present, and the interplay between these factors to explain the factors influencing ionisation energy and the trend in ionisation energy across period 3.

Introduction
Science instruction, from the elementary school to the university level, is frequently disappointing as far as promoting students’ understanding of science is concerned. Students are often in full command of science terminology and, for example, might be able to name the names of animals and plants, to write down the Schrödinger equation without any difficulties, or to provide key examples when presented with formulas. However, there very often is no deep understanding behind the facade of knowledge. (Duit & Treagust, 1995, p. 46).

Many researchers agree that the most important things that students bring to class are their conceptions (Driver & Oldham, 1986; Osborne & Wittrock, 1985). Duit and Treagust (1995) define conceptions as “the individual’s idiosyncratic mental representations” while concepts are “something firmly defined or widely accepted” (p. 47). Children develop ideas and beliefs about the natural world through their everyday life experiences. These include sensual experiences, language experiences, cultural background, peer groups, mass media as well as formal instruction (Duit & Treagust, 1995). Some of these ideas and beliefs, such as those about light and sight (Driver, 1995) may be similar across cultures as children have very similar personal experience with phenomena.

Students’ existing ideas are often strongly held, resistant to traditional teaching and form coherent though mistaken conceptual structures (Driver & Easley, 1978). Students may undergo instruction in a particular science topic, do reasonably well in a test on the topic, and yet, do not change their original ideas pertaining to the topic even if these ideas are in conflict with the scientific concepts they were taught (Fetherstonhaugh & Treagust, 1992). Duit and Treagust (1995) attribute this to students being satisfied with their own conceptions and therefore seeing little value in the new concepts. Another reason they proposed was that students look at the new learning material “through the lenses of their preinstructional conceptions” (p.47) and may find it incomprehensible. Osborne, Bell and Gilbert (1983) state that students often misinterpret, modify or reject scientific viewpoints based upon the way they really think about how and why things behave, so it is not surprising that research shows that students may persist almost totally with their existing views (Treagust, Duit, & Fraser, 1996). When the students’ existing knowledge prevails, the science concepts are rejected or there may be misinterpretation of the science concepts to fit or even support their existing knowledge. If the science concepts are accepted, it may be that they are accepted as special cases, exceptions to the rule (Hashweh, 1986), or in isolation from the students’ existing knowledge, only to be used in the science classroom (Osborne & Wittrock, 1985; de Posada, 1997) and regurgitated during examinations. Additional years of study can result in students acquiring more technical language but still leave the alternative conceptions unchanged (de Posada, 1997).

Chemistry is a difficult subject for most students because it involves “abstract and formal explanations of invisible interactions between particles at a molecular level” (Carr, 1984, p.97). Studies have shown that students have alternative conceptions in many chemistry topics (e.g. Garnett, Garnett, & Hackling, 1995; Nakhleh, 1992). In the topic of ionisation energy, Taber (1999, 2000a) found that students had alternative conceptions of the principles determining the magnitude of ionisation energy because they based their explanations on the octet rule/full shell framework – atoms try to gain full outermost shells or octets of electrons in the outermost shell, and only give them up, if at all, under extreme circumstances. He also argues that the students did not or could not apply basic
electrostatic principles that they learned in physics to explain the interactions between the nucleus and electrons in an atom. In addition, students also adopted an alternative explanatory principle, the ‘conservation of force’ conception, that is, that a charged body gives rise to a certain amount of force which is available to be shared amongst oppositely charged bodies. They thought that an atom’s electrons shared-out the attraction from its nuclear charge, so successive ionisations resulted in a greater share of the nuclear charge acting on each of the remaining electrons, resulting in increasing successive ionisation energies.

This paper describes a study undertaken in Singapore to determine if Grade 11 and 12 students (16 to 19 years old) had similar alternative conceptions and explanatory principles of the factors influencing ionisation energy as their A-level counterparts in the United Kingdom, as well as to explore students’ conceptions of the trend of ionisation energy across different elements in the Periodic Table. The extension of Taber’s study to also include students’ conceptions of the trend of ionisation energy was in line with requirements of the A-level chemistry syllabus on ionisation energy. In Singapore, students spend about 90 minutes of lectures on ionisation energy, during which the teacher would attend to the factors influencing ionisation energy, the trend of successive ionisation energies of an atom, and the trends of ionisation energy down a group and across Period 3. Students also spend about 45 to 90 minutes solving ionisation energy problems in class. They usually encounter ionisation energy again when they learn Hess’ Law in energetics and carry out calculations involving energy cycles. Teachers would also review the trend of ionisation energy with proton number across the third period when they cover chemical periodicity in inorganic chemistry. It has to be noted that the A-level chemistry does not include quantum mechanics, so no quantum mechanical explanations were used in Taber’s study as well as in this study.

Methodology
This study adopted the methodology outlined by Treagust (1995). The content framework of A-level ionisation energy was defined by a list of propositional knowledge statements,* a concept map (Figure 1) and a matching of the propositional knowledge statements to the concept map to ensure internal consistency. The propositional knowledge statements were either adapted from Taber’s (1997) work or identified from the A-level syllabus and two A-level textbooks. The concept map was drawn by the first-named author based on the propositional knowledge statements, the A-level syllabus, and the two A-level textbooks. A justification multiple choice instrument (see Appendix A) was developed and administered to 130 Grade 12 students from three schools. Eleven Grade 12 students who took the test were interviewed using the instrument as the interview protocol, to determine whether any item was ambiguous and to probe the reasons for their answers.

Results and Discussion
Students’ conceptions of ionisation energy are discussed under the sections: octet rule framework, conservation of force thinking, and relational based thinking (Driver et al., 1996).

Octet rule framework
When ionisation energy is supplied to a sodium atom, the valence electron is removed and the sodium ion (Na⁺) is formed. The sodium ion, however, can attract an electron to reform the sodium atom, releasing energy in the process. Thirty-nine students (30%) indicated in item 2 that a sodium ion would not combine with an electron to reform the sodium atom, with 21 students giving reasons to the effect that the sodium ion is already in a stable octet configuration and will not want to gain an electron to form the relatively unstable sodium atom. In item 4, 101 students (78%) indicated that the gaseous sodium ion is more stable than the gaseous sodium atom, with 85 students stating to the effect that the sodium ion had an octet/noble gas/full valence shell configuration so it was more stable than the sodium atom. Students also gave similar reasons during interviews, as illustrated below:

I: Why do you say it’s more stable?
S17: Because Na’ has...
S16: Octet structure.
S17: Yes...we learn that if it is completely filled, it’s more stable.

I denotes the interviewer; S16 & S17 denote students 16 & 17.

The findings above reflect the results obtained by Taber (1999) who found that 53 out of 110 A-level students (16 to 19 years old) believed that the “sodium atom would not be considered as stable as it does not have a full outer shell” (p. 101). He also found that a third of the students indicated that only one electron could be removed from the sodium atom as it then had a stable configuration. This was despite the fact that the students had studied patterns in successive ionisation energy. Taber (1997, 1999, 2000a) further investigated the octet rule framework by asking different groups of students which they thought was the more stable species, the sodium anion (Na⁻) or the sodium atom. The majority of the students responded that the sodium anion was more stable than the atom – a result later replicated, and extended to other examples such as the ions C⁴⁺ and C⁶⁺ which were judged more stable than a neutral carbon atom (Taber, 2002a). A significant minority of post-graduate trainee science teachers in the U.K. (Taber, 2000b) also believed that the anion (Na⁻) was more stable than the neutral atom. Thus, the octet rule framework seemed to be common among students and even among trainee-teachers. The authors believed that the octet rule framework was carried over from the learning of bonding in Grade 9 and 10 chemistry (14 to 17 years old) – for example, it was common to hear teachers say that ‘the sodium atom needed to lose an electron to achieve a stable octet electronic configuration’. Taber (2003) believes that the octet rule framework has internal coherence “because it comprises a range of ideas that are mutually self-

*A list of propositional knowledge statements is available from the first author.
Figure 1. Concept map of ionisation energy
supporting” (p. 102). This is further elaborated in the next section.

**Fully-filled and half-filled sub-shells**

An alternative conception that is related to the octet rule framework is that species with fully-filled or half-filled sub-shells are more stable than those without such electronic configurations. For example, in item 6, 11 students indicated that the first ionisation energy of magnesium was greater than that of sodium because magnesium has a stable fully-filled 3s sub-shell. The reason for the higher first ionisation energy of magnesium is that the increase in nuclear charge in the magnesium atom (12 protons in magnesium compared to 11 in sodium) outweighs the repulsion between the two electrons in the 3s orbital. However, these students seemed to believe that the higher ionisation energy was solely due to stability resulting from the filling of the 3s sub-shell; to disrupt the ‘stable’ filled 3s sub-shell configuration would require additional energy. Six students invoked the same reasoning to explain why the first ionisation energy of magnesium was higher than that of aluminium in item 7. The students did not realize that in this case, the diffuse character of the 3p orbital outweighs the increase in nuclear charge of aluminium compared to magnesium resulting in the lower first ionisation energy of aluminium.

A number of students exhibited ‘stable half-filled sub-shell’ thinking in items 9, 10 and 11. For example, 12 students in item 9 and 5 students in item 10 stated that phosphorus has a higher first ionisation energy than silicon and sulfur, respectively, because the 3p sub-shell of phosphorus was half-filled, hence more stable. They did not consider the higher nuclear charge of phosphorus compared to silicon, or the effect of the repulsion of paired electrons in one of the 3p orbitals of sulfur. This is illustrated by the following extract of an interview:

S4: Yes it would attract it even closer so itÉit
I: YesÉ
S4: Because the number of protons remain the same
I think first you are disturbing the stable structure of the
half-filled (sub-shell)...

It is not surprising that students had the alternative conception that a fully-filled 3s sub-shell and half-filled 3p sub-shell gave magnesium and phosphorus extra stability, respectively. Firstly, the ‘stable fully-filled or half-filled sub-shell’ thinking is a ‘logical’ extension of the octet rule framework, thus supporting it. Furthermore, teachers often use this as a rule-of-thumb to ‘explain’ the anomaly in the ionisation energy trend across periods 2 and 3 of the Periodic Table, and to help students remember the anomaly. A textbook on introductory tertiary chemistry (Lee, 1977) also used the octet rule framework and stable half-filled and fully-filled sub-shells to ‘explain’ the anomaly.

“The values for Ne and Ar are the highest in their periods because it requires a great deal of energy to break a stable filled shell of electrons*. There are several irregularities. The high values for Be and Mg are attributed to the stability of a filled s shell. The high values of N and P indicate that a half-filled p level is also particularly stable. The values for B and Al are lower because removal of one electron leaves a stable filled s shell, and similarly with O and S a stable half-filled p shell is left”

(Lee, 1977, p.96)

(*words in bold: emphasis by the authors)

Cann (2000) also commented that this “half-filled (and also completely filled) shells having intrinsic stability” reason was common and could be found in textbooks, but it offered “no explanation in terms of electrostatic or quantum mechanical interactions within the atom” (p. 1056).

Thus, the “stable half-filled and fully-filled sub-shell” thinking is very attractive to students and easily adopted by them because it seems to be a ‘logical’ extension of the octet rule framework and because they learned it during lessons or read it in textbooks.

**Conservation of force thinking**

In item 3, 79 students (61%) agreed with the statement that the attraction of the nucleus for the ‘lost’ electron would be redistributed among the remaining electrons in the sodium ion. This result is similar to that obtained by Taber (1999). A reason given by 29 of them was that since the same number of protons was attracting one less electron, the remaining electrons in the sodium ion would experience a greater attraction from the nucleus. An extract of an interview illustrating the conservation of force thinking is given below:

S4: Because the number of protons remain the same but the number of electrons has decreased…so it’s like there is a greater charge, a greater positive charge…attracting a less…1 mean a smaller negative charge…so it would attract it even closer.
I: Yes…
S4: Yes it would attract it even closer so it…it redistribute like…the total amount of…positive charge will attract the total amount of negative charge left after one electron has been removed.

The outermost electron of sodium is in the third shell which is shielded/screened from the nucleus by two electrons in the first shell and eight electrons in the second shell. The next electron to be removed comes from an inner shell which is closer to nucleus and experiences shielding/screening from only two electrons in the first shell. Hence the second ionisation energy of sodium is higher than the first because the second electron is more strongly attracted to the nucleus as it is nearer to the nucleus and experiences less shielding than the first electron; it is not higher because the attraction of the nucleus for the ‘lost’ electron would be redistributed among the remaining electrons in the sodium ion.

In item 5, 21 students who agreed that the second ionisation energy of sodium was greater than the first, gave the reason that force of attraction per electron has increased with the
earlier loss of an electron. Thus, in addition to the octet rule framework, students also use the conservation of force thinking to explain, in item 5, why the second ionisation energy of sodium is greater than the first.

Relation-based reasoning
Factors influencing ionisation energy include the nuclear charge, the distance of the electron from the nucleus and the repulsion and shielding/screening effect of the other electrons present. The results from items on the trend of the first ionisation energy across period 3 showed that students did not consider all the three factors but based their reasons exclusively on one or two factors. Driver et al. (1996) describe this type of thinking as relation-based reasoning, where ‘students tend to consider only one factor as possibly influencing the situation — the one which they see as the ‘cause’. As a consequence, other possible influential factors are overlooked’ (p. 115). For example, in item 6, 29 students stated that the first ionisation energy of sodium was greater than magnesium because the 3s electrons in magnesium were paired up and experience inter-electronic repulsion – this was opposite to the stable fully-filled sub-shell conception. It is true that there will be repulsion between the 3s electrons of magnesium, but in this situation, the effect of an increase in nuclear charge in magnesium outweighs the repulsion between the two 3s electrons. In addition, the spherical nature of the 3s orbital also allows the electrons to penetrate the screening effect of the inner shell electrons.

Many students also neglected the effect of nuclear charge when they gave the reason for ionisation energy decreasing across a period. These students believed that the more electrons an atom has, the further away the electrons are from the nucleus, or the greater the repulsion between the electrons. For example, 34 students stated in item 8 that sodium had a higher first ionisation energy than aluminium because the 3p electron of aluminium is further away from the nucleus compared to the 3s electron of sodium. Two students stated during interviews that they had this impression because of the filling of the orbital diagram of aluminium – they thought that putting an arrow in the first 3p box for aluminium indicated that the electron in the box was further away from the nucleus compared to the 3s electron of sodium. They did not realize that the orbital diagrams describe the relative energy levels of electrons of an atom; the diagrams cannot be used to compare distances of electrons from the nucleus of different atoms.

Implications
The results from the administration of the justification multiple choice instrument on ionisation energy and the interviews with students agree with many of the research findings on ionisation energy by Taber (1999, 2000a) in the United Kingdom. It seems that the A-level students in Singapore and the United Kingdom had very similar alternative conceptions, probably because they study similar content. The study also highlighted another area of student difficulty in ionisation energy, that is, the anomaly in the trend of ionisation energy across period 3. Since the students would hardly have encountered the concepts on ionisation energy in everyday life, it was likely that the alternative conceptions arose from the way ionisation energy was taught and learnt. As mentioned earlier in the paper, a textbook and A-level teachers also used the ‘stable fully-filled s sub-shell’ and ‘stable half-filled p sub-shell’ heuristics to explain, for example, why magnesium has a higher first ionisation energy than aluminium and why phosphorus has a higher first ionisation energy than sulfur. Since the octet rule framework did not conflict with the ‘stable fully-filled and half-filled sub-shell’ explanations, the ‘stable fully-filled and half-filled sub-shells’ explanation is readily accepted by students. Taber (2003) believes that some alternative conceptions in chemistry derive from “teaching that has attempted to avoid or ignore the more abstract aspects of the subject” (p. 106). Thus, the use of heuristics in the teaching of bonding and ionisation energy could be the most likely cause of the octet rule framework and the related ‘stable filled and half-filled sub-shell’ explanations.

The conservation of force thinking could have arisen because the students did not integrate the knowledge of electrostatics learned in physics with the concepts of ionisation energy learned in chemistry (Taber, 1998). Several students in the Singapore sample did not do physics at A-level, so they did not have the required knowledge of electrostatics at all!

Thus, the teacher has to review or introduce basic electrostatics during the introduction to ionisation energy. The teacher also needs to focus explicitly on the effects of nuclear charge, the distance of the electron from the nucleus and the repulsion/screening effect of the other electrons present, and the interplay between these factors, to explain the factors influencing ionisation energy and the trend in ionisation energy across period 3. The concept map (Figure 1) and list of propositional knowledge statements can be used to make explicit what exactly is required to learn ionisation energy, and help teachers not to overlook important concepts during their teaching (Tan, 2002). In addition, the teacher needs to point out any misleading material in textbooks that presents heuristics as explanations for anomalies in the trend of ionisation energy across a period. This could minimise the acquisition of the various alternative conceptions discussed in the paper, as well as students’ use of relational thinking where they only concentrate on one factor and ignore the rest.

Taber (2002b) proposes that students be taught the concept of core charges which be applied to explain ionisation energy, as well as electronegativity, bond polarity, bond fission and atomic size. Core charge, i.e. nuclear charge minus number of shielding electrons, is a useful concept at this level of study (where a simple approximation that electrons in inner shells shield electrons in outer shells). When the concept of core charge is understood by students, then it is possible to model explanations of ionization energy where there are only two major factors: core charge, and electron-nucleus distance. At present such recommendations are largely based on considerations of the conceptual structure of the subject, general knowledge about the nature of learning, and the specific results of
research into student thinking. Studies of student conceptions provide starting points, and learning theory suggests where teaching and learning can go wrong. When these factors are considered alongside analyses of the curriculum content (e.g. propositional knowledge statements and Figure 1) it is possible to propose change in teaching practice. It would be useful for future research to explore how student learning outcomes (as discussed in the present paper) might be related to the style and content of teacher presentations (for example, following the recommendations that arise from research such as the present study): however, the authors recognise the methodological difficulties inherent in such research.

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References

Appendix A
Examples of items in the justification multiple choice instrument
Sodium atoms are ionised to form sodium ions as follows:
Na(g) \rightarrow \text{Na}^+(g) + e^-

2. Once the outermost electron is removed from the sodium atom forming the sodium ion (Na’), the sodium ion will not combine with an electron to reform the sodium atom.
A True.
B False.
C I do not know the answer. ( )
Reason:

3. When an electron is removed from the sodium atom, the attraction of the nucleus for the ‘lost’ electron will be redistributed among the remaining electrons in the sodium ion (Na’).
A True.
B False.
C I do not know the answer. ( )
Reason:

6. Sodium, magnesium and aluminium are in Period 3. How would you expect the first ionisation energy of sodium (1s^2 2s^2 2p^6) to compare to that of magnesium (1s^2 2s^2 2p^6 3s^1)?
A The first ionisation energy of sodium is greater than that of magnesium.

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The ability of beginning university chemistry students to use ICT (information and communication technology) in their learning in 2002

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Abstract

There is an assumption that high-school students are becoming more computer literate, but published studies of specific skill level are lacking. An anonymous multiple-choice survey self-assessed the ICT (information and communication technology) skills of first-year chemistry students at the beginning of 2002. The general level of ICT skill continues to improve. There are minor deficiencies in the use of word processors, email attachments, the WWW, and in metacognitive skills. There are significant deficiencies in the use of spreadsheets, library databases, presentation software and computer conferencing, with major deficiencies in the use of relational databases.

Introduction

Universities are making increasing use of ICT (information and communication technology) in teaching and learning: eg (1, 2). The Australian Chamber of Commerce and Industry (ACCI) and the Business Council of Australia (BCA) have identified basic ICT skills as part of the framework of employability skills for the future (3); also see similar reports (4-6). Within the area of chemical education, Swift and Zielinski have identified the following as important ICT skills for undergraduate chemistry students (7): electronic record keeping; word processing; spreadsheets; (relational) databases; bibliographical databases; computer programming; instrument interfacing; information retrieval using the World Wide Web; and information retrieval from electronic journals, patent information and other specialised databases. Other researchers have also added the use of spreadsheets, electronic mail, computer conferencing, symbolic math software, molecular modeling software, graphing calculators, and simulation software to the list of desired skills (8-12). There have been several other publications on the importance and use of ICT in chemical education, of which (13-19) are a small selection. All of these publications implicitly assume that high-school students in the Western world are computer literate: in fact, (both federal and state) Australian government policy relies on this premise (20). However, informal discussion at the Chemical Education sessions of the 2000 RACI National Convention suggested that there is a significant number of university chemistry students who are less computer literate than politicians and university administrators assume. If students do not have the required level of ICT skills, then discussions on pedagogical issues related to ICT usage in the chemistry (or any) curriculum are moot. This paper is the third in a series, which seeks to provide numerical data (as opposed to assumption) about the actual level of specific ICT skill of students in the author’s first-year chemistry class at Deakin University: previous papers addressed student skill levels in 2000 and 2001 (21, 22).

This paper is the written version of a paper presented at the 2002 RACI Division of Chemical Education National Conference Rejuvenating the Learning and Teaching of Chemistry.

The study methodology

This study is based on student’s self-assessment of their ICT skills, using an anonymous multi-choice survey instrument in the first week of the academic year. It can be argued that such survey instruments measure the level of student confidence in ICT usage, which according to academic staff, teaching ICT courses, over-estimates the actual level of ICT skill (23). Furthermore, data from the University of Sydney showed that students in science-based faculties had more previous computer experience than the university average (24). Hence, the results of the project from this year and previous years (21, 22) should over-estimate the true ICT skill level across the university. In other words, the hypothesis of study is:

(All) university students’ true ICT skill level ≤ Science (chemistry) students’ true ICT skill level ≤ chemistry students’ perceptions of ICT skill.

The respondents were asked to agree or disagree with a number of statements using a 4-point Likert scale. Students were questioned about their general ICT competency, eg:

‘I can use word-processing programs’, as well as more detailed questions about particular ICT skills, eg:

‘I can insert tables in word-processing programs’, ‘I can use “styles” in word-processing programs.’

Some questions included information about the skill being assessed:

'http://FirstClass.deakin.edu.au/Login/ is a World Wide Web address or URL. I can use Web addresses or URLs.'

The survey instrument is similar to that used in previous years: the instrument used in 2000 can be found in (21).

Results and discussion

The survey sample group

The survey sample group consisted of the author’s first-year chemistry class at Deakin University. In 2002, this unit had approximately 100 students majoring in biological sciences, biotechnology, chemical sciences, forensic science, wine science, and some other disciplines: 49 students responded to the survey. This cohort consists entirely of ‘on-campus’ students. Reporting of the responses to the nearest percent has resulted in some round-off error (eg in Table 3, 10% + 17% = 26%). Binomial-
distribution standard deviations are reported in the Tables.

This first-year class consisted mainly of students (80% of respondents) in their first year of tertiary education, but a significant number had some previous tertiary education (10% in 2nd year, 2% in 3rd year, 8% in higher years). Students in 2nd and higher years of tertiary education did not have higher skill levels than 1st year students.

Although students in science-based disciplines are perceived to have a greater need of ICT competency, Lawson and de Matos have shown that a high level of ICT competency is also required of graduates in the humanities (25).

Survey Analysis

The survey was printed on a single A3 sheet in the form of a four-page “booklet” and responses were manually keyed into a computer for analysis. All analyses were done manually with standard statistical methods and formulas (26,27), using MS Excel for the calculations and data management. Tabulated uncertainties are one standard deviation based on the binomial distribution (students do or do not have the skill). On-line assessment was deliberately not used, as the survey results would be biased by students who are more computer literate.

There was a very small number of responses (<1%) which did not choose one of the four multiple-choice responses (Likert scale: 1-4): in most of those cases, there were written comments on the survey, which indicated that the student did not have that particular skill and responses of 1 (strongly disagree that ‘I can’) were recorded.

There were a small number of responses (<1%), which chose two multiple-choice responses (eg both ‘2’ and ‘3’), for a particular question. These cases were interpreted as the more-ICT-literate response in subsequent analyses for the following reason. The aim of the study is to determine deviations away from the assumption that students have ICT competency. Since we are effectively using a ‘proof by contradiction’ to challenge the assumption, the interpretation of these ambiguous responses as the more-ICT-literate response is equivalent to extending the ‘greatest lower bound’ of the set of students who have that particular ICT skill.

Responses ‘3’ and ‘4’ (agree or strongly agree that ‘I can …’) are combined in the following analyses as having the (self-) assessed knowledge or skill. Likewise, responses ‘1’ and ‘2’ are combined as not having the knowledge or skill.

Basic ICT skills

The ACCI and the BCA have identified that basic graduate ICT skills would involve the use of programs such as Word, Excel, PowerPoint and Lotus Notes, which are part of the everyday communication processes, and the use of programs to manage production processes (3). Educational institutions would add WWW-related skills, electronic-mail skills, computer-mediated communication (conferencing) and using library databases/catalogues to the list, because of the utility of these skills for research and on-line flexible teaching and learning (7,16,28,29).

Table 1 shows that most students have the skills required by employers and educational institutions, but there are some significant deficiencies.

All students reported being able to use word-processing software. Approximately 90% of students have the ability to use the WWW and electronic mail. These high levels of competency reflect the three types of software most commonly used in the high-school environment (24,30).

Table 1: Percentage of students having ICT skill to use a particular software type

<table>
<thead>
<tr>
<th>Software type</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
</tr>
</thead>
<tbody>
<tr>
<td>Word processing</td>
<td>99</td>
<td>98</td>
<td>100</td>
</tr>
<tr>
<td>Electronic mail</td>
<td>85</td>
<td>92</td>
<td>92 ± 4</td>
</tr>
<tr>
<td>World wide web</td>
<td>87</td>
<td>94</td>
<td>88 ± 5</td>
</tr>
<tr>
<td>Spreadsheet</td>
<td>88</td>
<td>77</td>
<td>80 ± 6</td>
</tr>
<tr>
<td>Library database</td>
<td>(a)</td>
<td>(a)</td>
<td>76 ± 6</td>
</tr>
<tr>
<td>Presentation software</td>
<td>(a)</td>
<td>(a)</td>
<td>63 ± 7</td>
</tr>
<tr>
<td>Computer conferencing</td>
<td>20</td>
<td>30</td>
<td>35 ± 7</td>
</tr>
<tr>
<td>Relational database</td>
<td>(a)</td>
<td>(a)</td>
<td>23 ± 6</td>
</tr>
</tbody>
</table>

(a) Not all ‘basic’ skills have been surveyed.

Implications for general university teaching and learning

Report and essay writing

Report and essay writing skills are essential in the university setting (31,32). However, unlike the humanities, technical writing in the sciences (including information technology, information systems and computer science) requires the use of superscripts, subscripts, special letters and symbols, equations, etc.

Table 2: Percentage of students having specific skill associated with word-processing.

<table>
<thead>
<tr>
<th>Word-processing skill</th>
<th>Know</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insert tables</td>
<td>94 ± 3 %</td>
</tr>
<tr>
<td>Use ‘styles’</td>
<td>92 ± 4 %</td>
</tr>
<tr>
<td>Insert superscripts and subscripts</td>
<td>78 ± 6 %</td>
</tr>
<tr>
<td>Type special letters and symbols</td>
<td>69 ± 7 %</td>
</tr>
<tr>
<td>Insert pictures and/or diagrams</td>
<td>67 ± 7 %</td>
</tr>
<tr>
<td>Insert equations</td>
<td>61 ± 7 %</td>
</tr>
</tbody>
</table>

Table 2 indicates that a significant proportion of students lack the ICT skills to write an acceptable technical report at the beginning of university.

Recommendation 1: Students should receive training in the use of word processors, with emphasis on specific skills, which are appropriate to their particular discipline.

Self-learning

One-third of students (33%) are unable to insert diagrams into word-processing documents while a larger proportion (41%) are unable to insert diagrams into presentations. The cross tabulations (‘correlations’) between responses yield much more useful information.

Table 3 shows 1 in 4 students (26%) are unable to transfer...
their skill from one situation to another: they are able to insert diagrams using one piece of software, but unable to do so using another, even though the software have the same “look-and-feel” and the same menu commands for inserting diagrams. This is consistent with a study that shows students at the start of university are unable to transfer mathematics skills from one context to another (33).

The desirability of metacognitive skills is well established in the educational literature (34-37). However, the time pressure for more ‘academic content’ usually regulates the ‘teaching’ of metacognitive and other study skills to the counselling and remedial tutoring services. Successful development of metacognitive skills depends on committing class time to skills development, and integration of this instruction both with the academic content and across the curriculum (38).

**Recommendation 2:** High school and university curricula should foster metacognitive skills, eg the ability to apply [the same] ‘problem-solving strategies across a range of areas’ (3).

**Electronic submission of assignments**

Most students are able to use electronic mail at the start of tertiary studies: 8% cannot. Table 4 shows that another 8%, who are able to use electronic mail, are unable to use attachments. While this is a significant improvement from 2001 (22), one in six students still do not have the skill for electronic submission of assignments.

**Recommendation 3:** Tertiary education institutions should not assume that students can submit assignments electronically, but should first train students in this skill.

**On-line teaching and learning via the WWW**

Educational institutions are making increasing use of the WWW (39). Textbooks and printed materials often cite URLs as sources of further information, for example (40):

‘For more information on the URLs we reference in this book … see the web page …

http://www.oreilly.com/catalog/devbioinfo/.’

Table 5 shows that while general WWW competency is extremely high, 1 in 8 students cannot use an URL to access a web site. There has been no significant change in this skill level since 2001 (22).

<table>
<thead>
<tr>
<th>Table 3: Cross tabulation of skill of inserting diagrams/pictures using different types of software.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insert diagrams in presentations</td>
</tr>
<tr>
<td>Do not know</td>
</tr>
<tr>
<td>Do not know</td>
</tr>
<tr>
<td>Know</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 4: Cross tabulation of knowledge of electronic mail and skill of attaching documents.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attaching documents to electronic mail</td>
</tr>
<tr>
<td>Do not know</td>
</tr>
<tr>
<td>Do not know</td>
</tr>
<tr>
<td>Know</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 5: Cross tabulation of WWW competency and skill of using URLs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>WWW</td>
</tr>
<tr>
<td>Don’t know</td>
</tr>
<tr>
<td>Know</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 6: Cross tabulation of WWW competency and skill of using URLs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>New search strategies</td>
</tr>
<tr>
<td>Don’t know</td>
</tr>
<tr>
<td>Know</td>
</tr>
</tbody>
</table>

This inability to search the WWW effectively parallels unquantified observations that students are unable to evaluate the *quality* of their ‘hits’ or retrievals. For example, information retrieved from websites of dubious political parties in foreign countries is given the same credence as official university or reputable government websites. There also seems to be a lack of understanding of copyright, ‘fair use’ and plagiarism issues, but a fuller discussion (eg 41, 42) is beyond the scope of this paper.

**Recommendation 4:** Tertiary education institutions should provide training for students to use the WWW effectively and ethically. In some instances, this ‘training’ might be as simple and easy as using 5 minutes of class time to demonstrate typing an URL into the appropriate box in a web browser.

<table>
<thead>
<tr>
<th>Table 7: Cross tabulation of WWW competency and skill of reading PDF files.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reading PDF files</td>
</tr>
<tr>
<td>Don’t know</td>
</tr>
<tr>
<td>Know</td>
</tr>
</tbody>
</table>

Table 7 shows that 43% of students do not know how to read portable document format (PDF or Adobe Acrobat format) files. Many more students probably have unconscious knowledge of how to access a web-linked PDF file using a pre-configured web browser. The significance of the 43% number is that if electronic teaching materials are disseminated to students as PDF via a non-WWW medium (eg diskette, CD-ROM, electronic mail attachment or electronic bulletin board), almost half the class may not know how to read the documents.
Recommendation 5: Students should receive training on how to recognise the file-name extension for PDF files and how to use the Adobe Acrobat Reader.

Numerical analysis, and plotting
The ACCI and the BCA specifically identified the use of spreadsheets in their framework of employability skills (3). The general competency and specific skills, associated with spreadsheet use, require improvement.

Table 8: Cross tabulation of spreadsheet competency and skill of analysing numerical data. Uncertainties are one standard deviation

<table>
<thead>
<tr>
<th>Use spreadheets to analyse numerical data</th>
<th>Use of spreadsheets</th>
<th>Don’t know</th>
<th>Know</th>
</tr>
</thead>
<tbody>
<tr>
<td>Don’t know</td>
<td>20 ± 6 %</td>
<td>18 ± 6 %</td>
<td></td>
</tr>
<tr>
<td>Know</td>
<td>61 ± 7 %</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 8 shows that 39% of students are unable to use a spreadsheet to analyse numerical data and to perform calculations.

Table 9: Cross tabulation of spreadsheet competency and skill of plotting numerical data.

<table>
<thead>
<tr>
<th>Use spreadsheets to plot numerical data</th>
<th>Use of spreadsheets</th>
<th>Don’t know</th>
<th>Know</th>
</tr>
</thead>
<tbody>
<tr>
<td>Don’t know</td>
<td>18 ± 6 %</td>
<td>18 ± 6 %</td>
<td></td>
</tr>
<tr>
<td>Know</td>
<td>2 ± 2 %</td>
<td>61 ± 7 %</td>
<td></td>
</tr>
</tbody>
</table>

Table 9 shows that 37% of students are unable to use a spreadsheet to plot numerical data.

The Australian high-school curricula and examination system encourages the use of programmable and graphics calculators, in preference over the use of spreadsheets. At the tertiary level, students are often encouraged to use specialised plotting (eg ORIGIN, IGOR, SIGMAPLOT, StatView, MINITAB, MATHCAD, MATHEMATICA) and other mathematical software (eg MATHEMATICA). The plethora of tools compounds the problem of lack of generic knowledge and skill transfer from one context to another (33).

Ehrmann has implied that spreadsheets are preferred over more specialised programs, because spreadsheets are perceived as being more ‘ordinary’ (ie ‘worldware’) and easier-to-use (43). Most students have access to spreadsheet software at home, without incurring additional licensing cost for the student or the university. Of course, the use of specialised software may still be required for upper-year studies in some disciplines.

The last quarter century has seen a shift away from logarithmic tables and slide-rules to electronic calculators. The latest shift, to programmable and/or graphics calculators, has decreased incentive and opportunity for the use of spreadsheet software in the high school environment. This author believes that use of programmable and/or graphics calculators should be avoided in favour of non-programmable calculators and spreadsheets for the following reasons. Firstly, the ‘real world’ of employment and tax returns requires the keeping of records, which is easily done with spreadsheets (printing creates a hardcopy). Secondly, the framework of employability skills specifically identifies the use of spreadsheets (3), not programmable and/or graphics calculators. Finally, many tertiary education institutions forbid the use of programmable and/or graphics calculators in examinations: students are permitted to use non-programmable calculators.

Recommendation 6: Greater use of spreadsheet software should be encouraged at high school, and the use of programmable and/or graphics calculators should be replaced by non-programmable calculators.

Recommendation 7: The use of specialised software (eg ORIGIN, IGOR, SIGMAPLOT, StatView, MINITAB, MATHCAD, MATHEMATICA) should be on a needs basis. Until that stage, students should be trained in the use of generalist (‘worldware’) spreadsheet software, which should be used across all disciplines to foster expertise in software that are in common usage in the general workforce outside universities.

Use of library databases and presentation software
Table 1 shows that most students have competency in use of library databases (76%) and presentation software (63%). Nevertheless, it would be desirable to increase the skill level of these two types of software.

Recommendation 8: Students should be trained in the use of library databases.

Recommendation 9: Students should be trained in the use of presentation software.

Collaborative learning via computer conferencing
Computer conferencing, ‘discussion spaces’ and other forms of computer-mediated communication are beneficial for the work (paid employment) environment, distance education, and for classes that span across multiple campuses. Most students (55%) know about computer conferencing or ‘discussion spaces’, but Table 1 and Table 10 show that only a minority (35%) of students have competency in the use of computer conferencing. Students who are enrolled ‘on-campus’ and who have regular contact with fellow students and teaching staff would have less need to use computer conferencing.

Table 10: Cross tabulation of knowledge about and ability to use computer conferencing.

<table>
<thead>
<tr>
<th>Know about computer conferencing</th>
<th>Don’t know</th>
<th>Know</th>
</tr>
</thead>
<tbody>
<tr>
<td>Don’t know</td>
<td>45 ± 7 %</td>
<td>20 ± 6 %</td>
</tr>
<tr>
<td>Know</td>
<td>35 ± 7 %</td>
<td></td>
</tr>
</tbody>
</table>

Recommendation 10: Students should be trained in the use of computer conferencing, ‘discussion spaces’ and other forms of computer-mediated communication, if it is appropriate to their particular learning environment.

Relational databases
The ACCI and the BCA identified ‘using IT to organise data’ as a desirable element of the framework of employability skills (3). This is normally done using relational databases (eg ACCESS, FILEMAKER).

With the vast increases in computing power over the last decade, the ability of ICT to store, sort, manipulate and
retrieve vast amounts of biological data has led to the new science of bioinformatics (eg (16,40)). While bioinformatics encompasses many areas of ICT usage applied to molecular biology, the most-rapidly-growing area of bioinformatics involves the use of relational databases (eg (16,40)). Many of the comments here about bioinformatics also apply to data mining.

Recommendation 13: University teachers should assume that university students have no knowledge of (relational) databases. This has particular implications for the teaching of database content within ICT, bioinformatics and other courses.

Recommendation 12: University students should receive general education on what databases are, and how they can be used (16,40).

Recommendation 11: University students should receive training in the use of (relational) databases, with emphasis on specific skills, which are appropriate to their particular discipline.

Implications for future investigations
A Telstra-commisioned study found that there has been significant growth in access to computers and internet access within Australia, but there is significant variation across community groups (44). Socio-economic factors such as low family income are the primary causes of the digital divide. It is unclear how the results of studies on the general population’s access to computers translate to the access to computers and ICT skills of different student groups.

There is some evidence suggesting that the ICT skills of science students should be better than the institutional average (24), but there is no conclusive data to confirm (or refute) this premise.

Recommendation 14: Studies, such as the one reported here, should be conducted to provide more data for the formulation of evidence-based policy.

Summary and Conclusions
This paper reports on the ICT skills of students enrolled in first-year chemistry, as evaluated by multiple-choice self-assessment. The 2002 results, presented here, indicate that the 2002 cohort have higher ICT skill levels than the 2001 and 2000 cohorts (21,22). However there are some deficiencies, which have significant detrimental implications for the teaching and learning practises of tertiary education institutions, and for the students’ future employability.

Minor deficiencies in the use of word processors, metacognitive skills, electronic-mail attachments, and use of the WWW were identified. There were significant deficiencies in the use of spreadsheets, library databases, presentation software and computer conferencing. Major deficiencies in the use of relational databases were noted, with many students (and some academic staff) not having any knowledge about relational databases.

The ICT skill results, of science students presented here, are believed to be better than the institutional average (24). Hence, the deficiencies in ICT skills would be exacerbated across an institution.

For the most part, these recommendations will be easy to implement, with the possible exception of the two specific recommendations 2 and 6 on metacognitive skills development and use of spreadsheets (instead of programmable and/or graphics calculators, specialised statistics, mathematics or plotting packages).

The desirability of metacognitive skills is well established. Although many academic teaching staff perceive skills development as outside the gambit of academic coursework, integration of the teaching of such skills is essential.

Greater use of spreadsheets and non-programmable calculators should be encouraged at high school because these are the skills required by both tertiary education institutions and employers.

Finally there is a need for continued monitoring of students’ ICT skills.

Acknowledgments
The author thanks Ms Jeanne Lee (Loyola College) for encouraging and neprui discussions. This research has been approved by the Deakin University Human Ethics Committee (EC 264-2001).

References
Continuation from page 26: Appendix A – Ions and ionisation energy

B. The first ionisation energy of sodium is less than that of magnesium.
C. The first ionisation energy of sodium is equal to that of magnesium.
D. I do not know the answer. (       )

Reason:

7. How do you expect the first ionisation energy of magnesium (1s² 2s² 2p⁶ 3s¹) to compare to that of aluminium (1s² 2s² 2p⁶ 3s³ 3p⁰)?
A. The first ionisation energy of magnesium is greater than that of aluminium.
B. The first ionisation energy of magnesium is less than that of aluminium.
C. The first ionisation energy of magnesium is equal to that of aluminium.
D. I do not know the answer. (       )

Reason:

8. How do you expect the first ionisation energy of sodium (1s² 2s² 2p⁶ 3s¹) to compare to that of aluminium (1s² 2s² 2p⁶ 3s³ 3p⁰)?
A. The first ionisation energy of sodium is greater than that of aluminium.
B. The first ionisation energy of sodium is less than that of aluminium.
C. The first ionisation energy of sodium is equal to that of aluminium.
D. I do not know the answer. (       )

Reason

* A list of propositional knowledge statements is available from the first author.
The Word on Chemistry

Allan Mitchell

Chemistry, University of New England

Back in the dim, dark, distant days of my innocence, there was an old ditty sung around infants’ schools which informed giggling juniors that, in contrast to their male counterparts, little girls were made from sugar and spice and all things nice. Well, I have now investigated such politically-incorrect assertions and can report that being nice basically means being ignorant, sugar is gravelly and spice needs some looking into.

It emerges that Romans looked kindly upon those with limited intellect, simply uttering nescire from ne- and scire for not and to know, the latter Latin terms expanding to negative and science while nescire nicely rounded down to nice.

Now, not every ancient type was nice but one could sweeten a visitor by offering bits broken from a crystallised mass of sticky plant extract. Sanskrits had economised on words by saying sakara when the subjects of gravel, grit or sugar arose, Persians later sweetening themselves with shaker, this entering Arabic as sukkar, Old French as sucre, New French as sucre and English as sugar. The process of breaking off produced Sanskrit bits called khanda which, in time, improved the income of the dental profession in the form of sugar candy. In the meantime, Greeks sucked on sakcharon and Romans sought saccharin, both allowing us to suggest saccharides. The hard sense of sakara lived on in the altered Greek form of kroko giving us crock pots, crockery and, from kroko and drilus (for worm), crocodiles, so named as they sunned their long bodies on gravelly river beaches.

Travel to the Spice Islands (the Moluccas, or Muluku of present-day Indonesia) was fraught with significant danger (not only from crocodiles) mixed in with the prospect of exorbitant profits. Spices were sought for their usefulness as medicines, preservatives and flavouring agents but spice has its origins in the Latin word species, describing an appearance, form or kind, perhaps as a species from Maluku. Ultimately, if we suspected something, we would specify an inspection (from specere, Latin to look) expecting to find something special. The sense of the word has altered to that with which it was once associated, much like the use of spices as drugs which actually describes the need for avoidance of moisture in storage, hence droge vate or dry casks, the Dutch droge relating to dry and drought and engendering drugs.

To have a suitable place of storage was and is of paramount importance to any spicy dealer in drugs, so much so that the Greeks merged their words for away and to put as apotithenai which somehow got twisted into apothecary. Old-world pharmacists would pharmakeuein or administer in the fashion of Lithuanians doing burti, ie practicing divination and magic.

Spices didn’t preserve everything (sometimes they just masked an unpleasant condition) but salts have been used for millennia. Crystalline sodium chloride, properly applied, would dehydrate foods and preserve them almost indefinitely. Saltpetre (potassium nitrate, or cubic saltpetre if sodium nitrate) was a useful oxidizing bactericide long before oxidants or bacteria were described as such. The salt part is obvious and the petre relates to the Latin petra or rock. Refined saltpetre, fused into little balls or cakes, was given the name of Salt Prunella with numerous variations, the prunella bit being a soft pronunciation of brunella, diminutive of the Latin brunus for brown. Various herbs had been used to treat the human and animal afflication of “the browns”, also curiously known as “brown tongue”, and salt prunella was used to treat and prevent the browning of foodstuffs on storage. Though someone named Prunella may be a little browned off at the notion, her name apparently harks from little plum or prune – not much to look at, perhaps, but actually rather sweet?

The Greeks also knew of a plant whose root or rhyza was sweet to the taste (sweet Greeks saying glykys and giving us glycerin) so they combined their observations and came up with glykkyrrhiza. In time, this entered Latin as glycyrrhiza, the g was dropped and the end bit altered producing liquorita then liquorice and licorice. This knowledge was indeed sweet as I had always been uncomfortable with the suggestion of liquor for solid licorice. Another suggestion of liquidity has its roots in the Greek forays into the lands of the barbarians, specifically a plant growing beside the river Rheu (actually the Volga to which the Greeks adapted rheum, their word for flow, hence diarrhoea, rheumatism and rheology) engendering the word rheumbarbarium, that is, rhubarb. This, as I recall, is not sweet, nor, reportedly, is the sorrel plant (oxalis to the Greeks and Romans), but both contain oxalic acid.

I’m somewhat mediocre about rhubarb (I don’t ever recall tasting sorrel) especially now as I find that the ac- or ox-bit in mediocre, oxalic and oxygen, and the ac- bit in acid, acetic, acid and acute are related, referring to the sharpness of a substance, object or sensation. Sharp edges get into the act; even eager spectators egging contestants up to the acme of a mountain or ocris. The acme is, of course, the pointy top edge of a mountain, this being altered to acme for smaller facial peaks. Oh, yes… mediocre. This term is reserved for un-fit types like myself who can’t pass the acid test and only manage to make it medi-ocris or half way up the mountain!
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